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Cobbossee Watershed Lakes Restoration
Hypolimnetic Treatment and Agricultural Waste Management

Cobossee Watershed District, Winthrop, ME

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COBBOSSEE WATERSHED LAKES RESTORATION:

HYPOLIMNETIC TREATMENT AND

AGRICULTURAL WASTE MANAGEMENT

by
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September 1982

Final Report

Project Officer
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PREFACE

The Cobbossee Watershed District's Lake Restoration Project was funded by Clean Lakes Program Grant #S001391010 from the U.S. Environmental Protection Agency, awarded in August 1977. This report describes the in-lake nutrient inactivation project and agricultural runoff control program implemented to restore three eutrophic lakes in the Cobbossee Watershed, and discusses the resulting water quality to date. The restoration project was directed by Thomas U. Gordon, Executive Director of the Cobbossee Watershed District. David R. Dominie coordinated the nutrient inactivation treatment of Annabessacook Lake; Katherine J. Sage coordinated the agricultural waste management program; Wendy L. Dennis directed the follow-up water quality monitoring.

We wish to acknowledge the cooperation and services contributed by the Maine Department of Environmental Protection (D.E.P.), primarily through the Division of Lakes and Biological Studies, directed by Matthew Scott. Technical assistance was provided throughout the entire project, as well as field services for both the in-lake treatment and water quality monitoring. We particularly want to thank Jeff Dennis, the D.E.P. project coordinator and a primary contributor to the project, as well as all other staff members of the Lakes Division who participated.

The D.E.P. Division of Laboratory and Field Services, directed by Gardner Hunt, analyzed all phosphorus samples and also provided technical assistance in the alum feasibility studies. We also wish to thank the Division of Oil Conveyence Services and other staff of the Bureau of Water Quality Control who provided substantial practical advice on the logistics of the alum treatment.

The U.S. Geological Survey, Water Resources Division, Augusta, Maine, provided technical assistance for hydrological data collection. They also provided field services for streamflow gage operation and maintenance and

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16. ABSTRACT
Annabessacook and Cobbossee Lakes and Pleasant Pond (Maine) all had high phosphorus concentration levels from agricultural runoff or nutrient cycling (internal phosphorus loading). Alum treatment in Annabessacook reduced internal phosphorus loads 70-80%, reduced phytoplankton biomass, changed species composition, and delayed algal blooms. Best management practices for animal wastes (building manure storage facilities) resulted in moderate improvement in transparency for Cobbossee Lake but neither this nor Pleasant Pond showed great improvements. This report was prepared in partial fulfillment of an EPA Clean Lakes Program grant.

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performed streamflow determinations and data processing.

A number of agencies contributed to the agricultural program. We appreciate the active participation of the Kennebec and Androscoggin County Offices of the U.S. Soil Conservation Service and the U.S. Agricultural Stabilization and Conservation Service, the Kennebec County Soil & Water Conservation District, and the Kennebec County Cooperative Extension Service. Special thanks go to the many farmers who made substantial financial commitments to implement the District's recommended pollution control practices on their farms.

The alum treatment of Annabessacook Lake was made possible by the assistance of many concerned citizens and organizations. The Annabessacook Lake Improvement Association was particularly generous in providing funding, equipment, and manpower for all aspects of the 1978 treatment. The Cobbossee Yacht Club also made a substantial contribution for acquisition of needed chemicals and equipment. The Maine National Guard also cooperated by transporting treatment equipment to and from the lake.

In addition to the principal author, a number of people contributed to this project report. Thomas Gordon wrote the section on the history of restoration efforts and edited the entire report. Katherine Sage wrote the section on the agricultural waste management program and portions of the diagnostic studies discussion. David Dominie authored a paper which served as the primary source for the discussion of the alum treatment. We also appreciate the phytoplankton and zoobenthos discussions prepared by Jeff Dennis and David Courtemanch, respectively, of the Maine D.E.P. Cobbossee Watershed District staff members who also contributed to the report are James Pray, graphics, and Pamela Baker, typing. We also appreciate the review provided by the D.E.P. Lakes Division, and the assistance of E.P.A. Project Officer Ronald G. Manfredonia.

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1. INTRODUCTION

This report discusses lake restoration activities in the watershed of Cobbossee Stream, which drains 562 sq km (217 sq mi) of Kennebec, Sagadahoc, and Androscoggin counties, immediately west of Augusta, Maine. The Cobbossee Watershed contains a chain of 24 lakes greater that 4 ha (10 ac). Three of these lakes (Annabessacook Lake, Cobbossee Lake, and Pleasant Pond) are culturally eutrophic and significant regional water quality problems.

Despite elimination of direct discharges of municipal and industrial effluent, nuisance algal growth persisted in the 1970's. Internal recycling from bottom sediments in Annabessacook Lake, immediately upstream of Cobbossee Lake and Pleasant Pond, and non-point source runoff from agricultural lands in the watersheds of all three lakes were identified as the primary sources of nutrient input.

The Cobbossee Watershed District was formed in 1973 as a local unit of government to protect and improve water quality in the watershed. A Clean Lakes Program grant in 1977 allowed the District to develop and implement a comprehensive restoration program for these three lakes, with assistance from the Maine Department of Environmental Protection. The program included hypolimnetic application of alum in Annabessacook Lake as a method of nutrient inactivation, and implementation of best management practices for agricultural pollution control in the direct drainages of all three lakes. This report summarizes the techniques utilized in the project and the water quality improvements to date.

The nutrient inactivation treatment was conducted in August 1978 to control phosphorus release from the bottom sediments of Annabessacook Lake.

Aluminum was used as the inactivating agent because of its low toxicity, effectiveness within the given pH ranges, and its inertness to redox changes. Both aluminum sulfate and sodium aluminate were used to prevent adverse ecological impacts from pH shifts. The treatment was done during mid-to late summer when hypolimnetic phosphorus concentrations were high. The chemicals were applied hypolimnetically to precipitate this increased phosphorus and to cover approximately 150 ha of anaerobic sediment. The application was intended as a one-time treatment to reduce phosphorus cycling within the lake, and thus hasten the lake's response to reductions in external nutrient loading.

Best management practices for agricultural pollution control concentrated on manure spreading on frozen or snow-covered ground. All major farms in the watersheds of the three lakes needed manure storage facilities for a 6-month winter period. Facilities were designed for the specific management needs and site conditions of each farm, and farmers were offered 50-percent cost-sharing on construction of the recommended facilities. Construction of the first manure storage facility began in 1978, and farmers continued to join in the project until its completion in December 1981. Through this program, 31 facilities were constructed to provide manure storage for approximately 80 percent of the animal units in the watersheds of the three lakes.

2. FINDINGS AND RECOMMENDATIONS

Monitoring results indicate significant improvements in Annabessacook Lake following the alum treatment, as measured by total phosphorus, chlorophyll-a, visibility, phytoplankton, and zoobenthos. Water clarity has greatly improved, although algal blooms have not been entirely eliminated. Both phytoplankton and zoobenthic populations demonstrated dramatic changes in species diversity. A substantial reduction in internal recycling and an increase in retention capacity of the bottom sediments has been achieved. External loading reductions were not apparent from the monitoring data. Some additional phosphorus reduction would enhance complete recovery of the lake.

Successful restoration of Annabessacook Lake was the primary technique for restoring Cobbossee Lake. Additional reductions in phosphorus loading were targeted in the direct drainage area of Cobbossee, particularly in the Jock Stream watershed. A substantial reduction in loading from Annabessacook has been measured in Jug Steam. Water quality improvements have not yet been observed in Cobbossee Lake; response time to external loading reductions is obviously longer than the immediate response to in-lake treatment observed in Annabessacook Lake. Monitoring did not show improved water quality in Jock Stream as of 1981; if improved agricultural waste management practices do not significantly reduce the phosphorus load to Cobbossee Lake in the near future, further reductions will be needed to eliminate the late summer algal blooms.

Response to reduced phosphorus loading were not apparent from monitoring in Pleasant Pond. Due to the prolonged construction period for the agricultural controls, monitoring would have to be continued to detect resultant water quality changes. Pleasant Pond does not have consistent summer algal bloom problems, but lower in-lake phosphorus levels are desired. The need for

further phosphorus loading reductions has not been determined. Specific findings for each lake are listed below.

ANNABESSACOOK LAKE

1. Internal loading was reduced 70% in the first summer following the alum treatment and 80% by the second summer.

2. The retention capacity of the lake sediments increased from -.32 in 1976 to .32 in 1980.

3. Oxygen depletion is still severe during summer and, consequently, high concentrations of phosphorus appear in the hypolimnion; however, the concentrations and phosphorus mass are considerably lower than before the in-lake treatment.

4. The maximum in-lake phosphorus concentrations which occur in late summer have been reduced from 76 to 35 ppb (volume-weighted).

5. The mean open water season phosphorus has been 24 to 26 ppb for the three post-treatment years, compared to 40 ppb in 1977.

6. The outflow concentrations (volume-weighted means) have decreased from 36 to 19 ppb P, thereby reducing the loading to downstream lakes.

7. Mean chlorophyll-a concentrations show a 60% reduction in 1979 and a 50% reduction in 1980; 1981 yielded a lesser reduction of 40% mean summer and 27% mean open water.

8. The phosphorus and chlorophyll increase and corresponding visibility decrease occurred later in the summer in the three post-treatment years.

9. Mean visibility for both the open water season and the summer has increased to greater than 3 meters.

10. Periods of visibility $\geq$ 4m have been observed every year since treatment, and new maximum visibility levels have been recorded.

11. Minimum visibility still reflects concentrated algae blooms ($<$ 2m), but the duration of algae blooms has been diminished, with visibility of 2m or greater for 79 to 100% of the open water season and 3m or greater persisting for more than 60% of the open water season.

12. Total phytoplankton volumes for two years after the alum treatment demonstrate reduced phytoplankton biomass, as evidenced by 1979 and 1980 maxima of 3.3 X $10^6 u^3$/ml and 6.3 X $10^6 u^3$/ml, respectively, compared to the pre-treatment maximum of 14.9 X $10^6 u^3$/ml in 1977.

13. The benthic community composition shifted from a eutrophic type community to a mesotrophic type following the alum treatment, with the dominant taxa changing from Chironomus plumosus and Procladius to Microtendipes, Paracladopelma, and Zalutschia.

14. The 1980 data suggest that additional external loading reductions of 9 and 27% would be needed to attain lake concentrations of 15 and 12 ppb phosphorus.

COBBOSSEE LAKE

1. Incoming phosphorus from Annabessacook Lake has been reduced from approximately one half of Cobbossee Lake's total load before the alum treatment, to one third of the total load monitored in 1979 through 1981.

2. An additional 20% reduction of phosphorus in Jug Stream (Annabessacook Lake outlet) would achieve the critical concentration of 15 ppb targeted for this phosphorus source.

3. Phosphorus loading from Jock Stream remained excessive throughout the project monitoring period; at least a 50% reduction would be needed to achieve desired phosphorus levels in Jock Stream.

4. Below normal runoff, lack of snowcover, and the low flushing rate of Cobbossee Lake in 1980 and 1981 are believed to have influenced both the high phosphorus concentrations in Jock Stream and Cobbossee Lake's lack of response to Jug Stream phosphorus reductions.

5. Cobbossee Lake phosphorus concentrations did not decrease during the project; mean concentrations of 15 to 18 ppb, however, classify the lake as less eutrophic than either Annabessacook Lake or Pleasant Pond.

6. Cobbossee Lake exhibits very good water quality, as measured by chlorophyll and visibility, until August or September, at which time a dramatic change occurs in both parameters; accompanying phosphorus levels were not particularly high, nor did they increase correspondingly.

7. The north basin of the lake experiences a more severe algal bloom than the south basin, as evidenced by lower visibility and higher chlorophyll-a concentrations.

8. Chlorophyll-a levels do not indicate water quality changes in the south basin; the north basin peak chlorophyll concentrations increased during the project period, reflecting more intense algal blooms.

9. A moderate improvement appeared in visibility in the south basin, although undesirable late summer visibility (<3m) still persists, including a few days of <2m visibility. Visibility during late summer algal blooms in the north basin has declined, with a minumum visibility of 1.1m observed in each of the last three years.

10. External phosphorus loading still appears to be the major impediment to recovery of Cobbossee Lake. Some high phosphorus concentrations were found in the extensive zone of anoxia in the north basin; the potential exists for this to become a significant phosphorus source if excessive external phosphorus loading continues.

11. Lower phosphorus concentrations observed in Jock Stream in 1982, together with continued maintenance of reduced phosphorus loading from Annabessacook Lake, provide optimism for eventual improvement in Cobbossee Lake. In-lake responses are expected to appear first in the south basin, which receives both tributaries.

PLEASANT POND

1. Tributary monitoring during late winter and early spring showed that agricultural runoff from non-cooperating farms continued to generate excessive phosphorus loading to Pleasant Pond; two large farms which were found to be significant problems eventually participated late in the program.

2. In-lake phosphorus concentrations did not show a decrease during restoration monitoring and are above desireable levels.

3. Both before and after the restoration project, occassional late summer phosphorus increases were observed that may be caused by phosphorus recycling within the lake; the pond did not have a phosphorus-rich anaerobic hypolimnion and thus the phosphorus source was probably littoral.

4. The elevated surface phosphorus concentrations and the phosphorus, chlorophyll, and visibility relationships in Pleasant Pond are probably a function of its high color.

5. High chlorophyll concentrations associated with intense algal blooms were not consistently recorded, and the most recent chlorophyll data indicated the absence of such conditions. Further monitoring would be necessary to define a trend of improvement.

6. Visibility did not drop to the low levels observed in 1975 and 1976; it cannot be established that the improved visibility relates to reduced agricultural runoff, since improvements were noticed prior to phosphorus control.

7. Visibility generally remained above 2 meters and averaged 3.2 to 3.7m. Algal blooms were intermittent and not confined to blue-green species.

3. PROJECT AREA DESCRIPTION

The Cobbossee Stream Watershed is a 562 sq km (217 sq mi) sub-watershed of the Kennebec River basin, the third largest river basin in the State of Maine. Within the Cobbossee Watershed, there are 24 named lakes and ponds totaling 53.6 sq km (13,250 ac) ranging in size from 0.07 sq km (18 ac) to 22.42 sq km (5,543 ac). Annabessacook Lake, Cobbossee Lake, and Pleasant Pond comprise a total of 31.19 sq km or 58 percent of the lake surface area in the Watershed. Morphometric data for the three lakes are presented in Table 1.

Table 1: Lake Morphometry and Drainage Area

		Annabessacook Lake	Cobbossee Lake	Pleasant Pond
Surface area	(km^2)	5.74	22.43	3.02
Mean depth	(m)	5.3	8.1	2.3
Maximum depth	(m)	14.0	30.5	7.9
Volume	($10^6 m^3$)	29.47	157.07	6.96
Hypolimnion volume	($10^6 m^3$)	3.54	31.41	
Flushing rate	(yr^{-1})	4.7	1.18	5.59
Direct drainage area	(km^2)	56.0	121.0	155.1
Total drainage area	(km^2)	220.2	341.1	561.8

Precipitation in the Cobbossee lakes region has been recorded at East Winthrop, Maine since 1931. From these data, collected by the Augusta Water District though 1977 and subsequently by the Cobbossee Watershed District through 1982. mean annual precipitation is 106.73 cm (42.02 inches) and is distributed relatively uniformly throughout the year. Monthly averages range from 7.62 cm (3.00 inches) in August to 11.02 cm (4.34 inches) in November. Data from the East Winthrop station for 1931-1961 has been compiled by the National Weather Service, USDC. Snowfall averages 187.96 cm/yr (74 inches) with individual annual snowfall varying widely. Temperatures

range from -35°C (-31°F) to 36°C (97°F). Minimum temperatures of 0°C (32°F) or below occur an average of 163 days during the year. Average summer temperatures range from 18.3°C (65°F) to 21.1°C (70°F).

According to the U.S. Department of Agriculture, Soil Conservation Service Technical Paper #40, "Rainfall Frequency Atlas of the United States" (1961), the 25-year 24-hour storm is 12.7 cm (5.0 inches), and the 25-year 1-hour storm is 4.3 cm (1.7 inches). The storm of record occurred September of 1954, in which 14.68 cm (5.78 inches) of rain fell in 24 hours.

U.S. Geological Survey data for the area indicates average annual runoff to be approximately 63.5 cm (25 inches) per year. The watershed is gaged at a site 0.6 km (0.4 mi) upstream from the confluence with the Kennebec River. The average discharge of Cobbossee Stream for 79 years of record (USGS, 1981) is 9.66 m^3/s (341 ft^3/s). A maximum discharge of 142 m^3/s (5,020 ft^3/s) occurred on March 21, 1936. The minimum discharge has been restricted to leakage only when gates in upstream dams were closed. Hydrologic and climatologic information for the project period is summarized in Table 2.

Table 2: Climatologic and Hydrologic Summary for Project Period*

	Precipitation, cm[a]			Cobbossee Stream Flow[b]		
	annual total	annual snowfall	largest storm	cm runoff	mean daily flow, m^3/s	maximum flow, m^3/s
1977-78	131.16	243.84	6.8	86.08	15.35	53.52
1978-79	119.38	187.96	11.99	60.45	10.79	56.63
1979-80	94.94	70.87	6.73	52.17	9.26	49.55
1980-81	100.28	103.89	5.5	35.08	6.26	20.13

* Based on water year October 1 - September 30.

[a] Data collected by Cobbossee Watershed District; [b] U.S. Geological Survey data.

The Soil Survey of Kennebec County, issued August, 1978 by the U.S. Soil Conservation Service, describes major soil associations in the county. In the Cobbossee Watershed, three soil associations predominate:

1. Hollis - Paxton - Charlton - Woodbridge association: found on upland ridges generally at elevations of 61 to 213 meters. The major soils in this association were formed in glacial till. Hollis, Paxton, and Woodbridge soils have a high runoff potential (soil hydrologic class C) due to shallowness to bedrock and high water table conditions; Charlton soils have a moderate runoff potential (soil hydrologic class B). All except Hollis have infiltration rates of less than 2.54 cm per hour. Soil erodibility is high.

2. Buxton - Scio - Scantic association: found in flat areas near waterways. The major soils in the association were formed in marine and lacustrine sediments. All of these soils are characterized by wetness and low infiltration rates (soil hydrologic class C and infiltration rates less than 2.54cm/hour). Soil erodibility is high.

3. Scantic - Ridgebury - Buxton association: found in valleys and on upland ridges. The major soils in this association were formed both by marine or lacustrine sediments and by glacial till. All of these soils have a high runoff potential (soil hydrologic class C) and low infiltration rate (less than 2.54cm/hour). Soil erodibility is high.

The surficial geology of the watershed has been mapped and reported by the Maine Bureau of Geology (April 1976). The surficial geologic deposits are unconsolidated sediments overlying bedrock. The oldest and most abundant materials are products of continental glaciation. The Cobbossee Lakes area shows a predominance of glacial till. Bedrock outcrops are common, as are shallow - to - bedrock areas (less than 3.05m). Areas also exist with depth to bedrock exceeding 61 meters although this is uncommon. Till varies from a fine grained silty matrix commonly known as "hardpan" to a loose, sandy material. Other surficial deposits include sand and gravel, glacial-lake deposits, marine silt and clay, windblown sand, recent alluvium and swamp deposits.

Groundwater resources in the watershed associated with till deposits

on fractured bedrock generally will support water supplies for individual homes. Some areas containing gravel aquifers in Monmouth, Litchfield, and Manchester may produce yields sufficient for municipal water wells. Areas of exposed sand and gravel and thick till provide recharge to the groundwater.

TORSEY LAKE
MARAMACOOK LAKE
WINTHROP
AUGUSTA
COBBOSSEE CONTEE LAKE
ANNABESSACOOK LAKE

4. HISTORY OF RESTORATION EFFORTS

Annabessacook Lake has long had the reputation as one of the most polluted lakes in the State of Maine. In the early 1940's, the first formal complaints of algae blooms on the lake were recorded. Complaints indicated that the lake became "pea soup" green every summer, often with thick scums of microscopic algae accumulating on the surface and heavy mats of leafy vegetation rotting on the shorelines. From 1964 through 1971, residents responded by treating Annabessacook with 30 tons of copper sulfate algacides, but the effect was short-lived and diminished with each season as resistant types of algae began to predominate.

Phosphorus is the nutrient controlling algal growth in most lakes of the northern United States and Canada, and for many years, the industries and towns surrounding Annabessacook Lake discharged large quantities of phosphorus in their untreated wastes. These effluents stimulated the growth of algae in Annabessacook Lake and, subsequently, in Cobbossee Lake and Pleasant Pond downstream. Although numerous investigations of the lake were conducted, no action was taken to eliminate the discharges until 1970.

The first step toward lake restoration was elimination of the direct discharges of municipal and industrial effluent to Annabessacook Lake. In 1967, Maine's Water Improvement Commission found that Annabessacook Lake received over 13,600 kg (30,000 lb) of phosphorus per year, and that the surface waters of the lake contained enough phosphorus to produce about 770,000 kg (1.7 million lb) of algae. Municipal and industrial discharges from the village areas of Winthrop, North Monmouth, and Monmouth Center accounted for 93 percent of this annual phosphorus input.

To continue discharging into the lakes would have required costly advanced wastewater treatment to remove phosphorus. In 1969, the Augusta Sanitary District chose a more economical alternative and began building a trunkline sewer from

Winthrop to the wastewater treatment plant in Augusta, a distance of approximately 19 Km (12 mi). The trunkline became operational in 1972, and was then extended to Monmouth in 1976, so that all point source discharges of phosphorus to the Cobbossee Watershed lakes had been eliminated.

Annabessacook Lake showed some improvement as a result of the diversion of point sources. However, the lake's ambient total phosphorus concentrations remained above 15 micrograms per liter (ug/l), the generally accepted threshold level for algal blooms in northern lakes. Continuing nuisance growth of algae in Annabessacook Lake, Cobbossee Lake, and Pleasant Pond indicated that the problem of cultural eutrophication had not yet been solved.

Aerators were also installed in Annabessacook Lake in 1972 and 1974 in an effort to accelerate its recovery. The intent of the aeration project was to destratify the lake and mix the water layers, thereby oxygenating the hypolimnion, cooling the epilimnion, and diluting the surface algal concentrations. It was determined that a simple aeration system could be set up by lakeshore property owners for summer use. However, the aeration project failed to mix lake water beyond a radius of 50 m. Because of Annabessacook's size, the project did not result in any noticeable water quality improvements, and may even have caused a net nutrient input by stirring up the phosphorus-rich sediments at the bottom of the lake.

Bottom sediments were a major focus of the early restoration plans. It was presumed that the bottom sediments were made up primarily of residues from the many years of sewage discharge into the lake. The shallow northern end of Annabessacook, the former discharge point for municipal and industrial effluent from Winthrop, was a particular focal point for concern. Bubbling water and foul odors caused by decaying vegetation, together with the proximity of the area to the old sewage outfalls, pointed toward this area as a significant source of nutrient loading

continuing in the lake. However, subsequent sampling of bottom sediments indicated high nutrient levels over the entire lake bottom, not just the north end. Thus, dredging or marsh propagation in this restricted area would not result in any substantial restoration of water quality in the lake as a whole.

Immediately downsteam from Annabessacook Lake, Cobbossee Lake also developed water quality problems. While the lake enjoyed a national reputation as a sport fishery, there were growing concerns in the 1960's about declining water quality. A summary of Cobbossee Lake fishing by the Maine Department of Inland Fisheries and Wildlife in 1977 noted that "as recently as the early 1960's, the lake was suitable for lake trout and landlocked salmon management, but in the 60's, the water quality deteriorated to the point that the lake became unable to support the lake trout fishery. By the early 1970's, the salmon fishery had collapsed as well". Growing complaints from citizens in the late 1960's led to conferences in Winthrop and at the University of Maine on lake reclamation. These sessions resulted in the proposal of the Cobbossee Watershed District as a regional lake restoration agency.

Pleasant Pond does not have a well-documented history of water quality problems. A shallow impoundment, the lake experienced intermittent algae problems throughout the 1970's. Some incidents of excessive algae may have been caused by upstream discharges of water from Cobbossee Lake during that lake's blooms. However, algae blooms have also been apparent in areas of Pleasant Pond that are isolated from the Cobbossee Stream inlet. Since Pleasant Pond has been a major source of the public water supply for the City of Gardiner, the presence of blue-green algae blooms (whether stimulated by in-lake or upstream nutrient sources) required increased water treatment.

Frustrated by 30 years of failure in improving water quality in the Cobbossee

chain of lakes, lakeshore property owners, local officals, and concerned citizens began working to develop a strategy for lake restoration. Realizing that the causes of lake water pollution are most often found not within the lake itself, but rather in the various land use activities within the watershed that contribute pollutants through surface runoff or ground water, they formed the Cobbosseee Watershed District in 1972. The District was designed to function as a quasi-municipal, special-purpose district (similar to a school district or sewer authority) to pursue a comprehensive approach to water quality management in the watershed.

The special-purpose lake district has several advantages for the resolution of water quality problems:

- Jurisdication over the entire watershed, which extends beyond the boundaries of any single municipality;
- Taxation powers which free it from the competition for often limited tax revenues raised by a general-purpose goverment; and
- Specialized technical staff to deal with lake management problems and communicate with their counterparts in State and Federal agencies.

Since 1973, the District has been operated by a 13-member board of trustees, representing the municipalities and three water supply districts which joined. The District has raised from $25,000 to $40,000 per year by local tax assessments to support its ongoing water resource programs. Additional support has come from federal grants under section 208 (water quality planning) and 314 (lake restoration) of the Clean Water Act.

Prior to implementation of the lake restoration project, diagnostic studies of Annabessacook Lake, Cobbosse Lake, and Pleasant Pond were conducted by the Cobbossee Watershed District as part of the 208 areawide water quality management

planning process for the Southern Kennebec Valley (Sage and Moran. 1977). These studies formed the basis for the District's application for a Clean Lakes Program grant.

The Clean Lakes Program was initiated by the U.S. Environmental Protection Agency in 1975 to implement section 314 of the Federal Water Pollution Control Act Amendments of 1972. Section 314 gives the States the responsibility for protecting and restoring the quality of freshwater lakes. The program has provided funding to assist the States in classifying their lakes according to water quality, identifying methods to control pollution sources affecting them, and restoring those which have been degraded. To qualify for a Clean Lakes Program grant for restoration, a lake must be accessible to the public, and the proposed restoration project must have the potential to yield long-term public benefits. The Cobbossee Watershed District received a Clean Lakes Program grant in August 1977.

5. DIAGNOSTIC STUDIES

The diagnostic studies provided an analysis of the relationships of land use and phosphorus loading in the lakes' watersheds. Comparison of phosphorus budgets with existing water quality and assimilative capacities calculated by lake modeling techniques determined the phosphorus loading reductions needed. The quantification of phosphorus contributions from various land uses and other non-point sources suggested alternatives for achieving needed reductions.

Data collection for the detailed lake management studies required expansion of the limited data base, particularly for Cobbossee Lake and Pleasant Pond water quality. Thus, the District established an intensive monitoring program for the three lakes in cooperation with the Maine Department of Environmental Protection. The lakes were monitored in 1975 from spring overturn (mid-April) to fall overturn (mid-October) every ten days; monitoring included secchi disk visibility, dissolved oxygen and temperature profiles. In 1976, lake sampling occurred biweekly from spring to fall overturn for secchi disk visibility, chlorophyll-a and total phosphorus. Oxygen and temperature profiles were reduced to four times yearly.

Monitoring of the 12 major tributaries to Pleasant Pond, Cobbossee and Annabessacook Lakes occurred monthly during base flow conditions (July - August; December - March) and weekly to biweekly during spring and fall runoff periods (April - June; September - November). Parameters monitored included total phosphorus, ammonium nitrate, total Kjehldal nitrogen, nitrate - nitrite nitrogen, dissolved oxygen, turbidity, suspended solids, and total coliform bacteria. While phosphorus was of primary interest in the lake studies, the other parameters provided some indication of the source

of elevated phosphorus levels (i.e. animal waste, erosion/sedimentation, urban runoff, etc.)

Flow determinations for the lake tributaries were obtained through measurements taken at the time of sampling at staff gages or use of U.S. Geological Survey reference points, with U.S.G.S.-verified rating curves for corresponding flows. Mean monthly flows were provided by the U.S.G.S. based on these measurements. Jock Stream, a tributary to Cobbossee Lake, was the subject of an agricultural runoff research effort, and thus, was monitored more frequently. A theoretical hydrograph for Jock Stream was prepared based on water stage measurements and correlations with hydrographs produced from a recording gage on a nearby river.

Morphometric data on the lakes were not readily available, except for surface area. Mean depth was calculated for each lake using depth soundings available through the Maine Department of Inland Fish and Wildlife lake surveys. Lake volumes and percent hypolimnion were calculated using bathymetric contours plotted from these soundings. Drainage areas were measured by the U.S.G.S standard procedure of quadrangle division using a compensating polar planimeter. Flushing rates were calculated using lake volume, drainage area and average unit runoff for this area.

Land use information was provided by aerial photo interpretation using 1974 U.S. Soil Conservation Service photographs of the lake drainages. Twelve land use categories were mapped, including undisturbed forests (crown canopy height greater than 4.6 meters and closure exceeding 50%), disturbed forest (a recent selective cut or clearcut in advanced succession with crown canopy height less than 4.6 meters and closure from 10 to 50%), severely disturbed forest (clearcut, less than 4.6 meters in height and less than 10% closure), tilled fields, pasture, sand and gravel mining,

orchards, reverting fields, dense urban development, village/suburban development, water, and wetlands. Acreages by category were analyzed using planimetric methods.

Information on shoreland sewage disposal, originally suspected as a primary contributor to lake degradation, was obtained through a door-to-door survey in 1974 and in 1975. Approximately 50 percent of the homes located within 76.2 m of the shore of the three lakes were surveyed (529 individual reports). Information collected included type of disposal system, distance of the system from the lake, soils and slope conditions, frequency of maintenance, number of occupants and duration of occupancy and presence of malfunctions (determined through on-site investigation and dye tests).

Several approaches for determining the annual phosphorus loadings to the lakes were selected:

- Determination of phosphorus runoff rates from various land uses and applying these to land use information for the direct drainage of the lake. Phosphorus runoff rates were selected from values reported in the literature, with one exception. Detailed monitoring was conducted on a small tributary to Cobbossee Lake, Jock Stream, to determine phosphorus runoff rates from agricultural lands.

- Calculation of phosphorus loading by lake tributaries through monitoring of phosphorus concentrations and stream flow - a measure of loadings from upstream as well as direct drainage.

- Monitoring of in-lake phosphorus at spring and fall overturn and calculation of the amount of phosphorus loading necessary to achieve that concentration using the Dillon and Rigler (1974) lake model.

- Calculation of internal loadings from lake sediments by means of a mass balance formula comparing the phosphorus change in the lake with the difference in phosphorus inputs to the lake (via tributaries, precipitation and shoreland drainage) and export from the lake.

- Estimation of internal loadings from lake sediments using release rates from the literature and mapping the zone of anoxia in the lake.

In general, results from the various methods corresponded reasonably well. Loadings estimated by land use in the direct drainages were verified by tributary loading calculations when contributions from upstream lakes were factored out. Phosphorus

export from upstream lakes was calculated using the Dillon lake model(1974). The lake model was also used to compute total annual loading to each lake, and was verified by the tributary loading estimates.

The phosphorus budget studies allowed the Cobbossee Watershed District to prioritize nutrient sources for control. Shoreland septic systems, once considered a significant contributor to lake degradation, were found to contribute less than one percent of the phosphorus loading to the lakes.

Runoff from agricultural lands became a major concern, comprising the greatest single source of phosphorus to Pleasant Pond, and the second most significant phosphorus source of Annabessacook and Cobbossee Lakes. Phosphorus runoff rates used in making these determinations were obtained through a detailed study of Jock Stream, a tributary to Cobbossee Lake. The Jock Stream drainage includes agricultural operations which are typical of the region - primarily dairy farms with a low percentage of cultivated land (less than 1%). Phosphorus runoff rates from agricultural lands exceeded natural background levels by a factor of 50. Thus agricultural lands, comprising only 20% of the land area in the direct drainages of the lakes, contributed 60-80% of the phosphorus loading attributed to direct drainage, and 24-80% of the phosphorus loading from all sources to the lakes. The widespread practice of spreading manure on frozen and snow-covered ground was determined to be the most likely agricultural pollution problem. In 1975-76, over 70% of the phosphorus loss from agricultural lands was estimated to have occurred in the winter period from November through April.

Internal recycling of phosphorus from lake bottom sediments was determined to be the primary impediment to Annabessacook Lake's improvement. The calculated flushing rate (p) of 4.7 flushes per year for 1975-76 implies a theoretical phosphorus retention coefficient for Annabessacook of .32.

by use of the Larsen and Mercier formula (1976):

$$R = \frac{1}{1 + \sqrt{p}}$$

where: R = the percent of incoming phosphorus retained by the bottom sediments

p = the annual flushing rate, yr^{-1}

In other words, 32% of the phosphorus entering the lake should be deposited in the sediments and remain there; the rest would determine the concentration in the lake and its outflow. A major finding of the Annabessacook Lake study, however, was that the phosphorus retention by sediments was significantly less than the theoretical 32%. In fact, the phosphorus monitored at the outlet exceeded the incoming phosphorus. From the data 3460 kgPext - 4585 outflow = -1125 kg, and -1125/3460 = -.32 = R. Whatever portion of the influent phosphorus settled out, an equivalent amount was recycled during the year, as was phosphorus deposited in previous years.

Internal recycling of phosphorus in 1976 from spring overturn to late summer, when in-lake P concentrations were at their highest for the summer stratification season, was calculated as: (Cooke et al., 1977)

$$\Delta P_{lake} - (P_{ext} - P_{outflow}) = P_{internal}$$

$$\underset{\text{Apr-Aug}}{+1143} - (670 - 1400) = 1873 \text{ kg.}$$

where: ΔP_{lake} = the change in the amount of in-lake phosphorus from $time_0$ to $time_1$

P_{ext} = phosphorus inputs to the lake from external sources including: Tributaries, precipitation, overland flow from shoreland drainage and groundwater

$P_{outflow}$ = phosphorus losses due to outflow

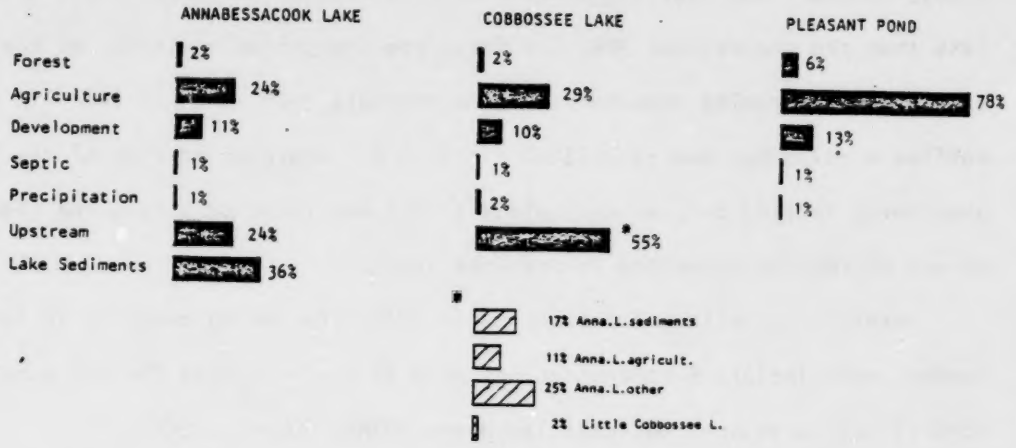
$P_{internal}$ = phosphorus inputs from internal sources.

A similar amount of internal recycling was calculated in 1977 from June to mid-September when the in-lake phosphorus maxima occurred at the onset of fall overturn:

$$\underset{\text{Jun-Sep}}{+1540} - (224 - 475) = 1791 \text{ kg.}$$

A second method, use of phosphorus release rates reported by Vollenweider (1968) yielded a more conservative estimate of 1100 kg. Thus phosphorus release from lake bottom sediments during periods of anoxia was estimated to contribute approximately 1500 kg and constitute 36% of the total phosphorus budget to Annabessacook Lake in 1976. Furthermore, Annabessacook Lake contributed a majority of the total phosphorus loading to Cobbossee Lake, directly downstream. Figure 1 illustrates the phosphorus sources to each of the three lakes.

Figure 1: PHOSPHORUS SOURCES



Having calculated annual phosphorus budgets for each of the three problem lakes, the phosphorus loading reduction needed to achieve restoration had to be determined. This required defining water quality goals and standards. The primary goal was to reduce productivity in the lakes to achieve acceptable water clarity. Phosphorus, chlorophyll-a, and secchi disk visibility monitored in 1975-76 in 26 lakes were correlated through regression analysis. From these regressions, an overturn phosphorus concentration of 15 ppb[1], believed to be a critical limit beyond which nuisance algae blooms would occur, was found to correspond to an average summer secchi disk visibility of 4.3 m and an average summer chlorophyll-a concentration of 5.6 ug/l. The Cobbossee Watershed

[1] ppb=ug/l; Maine D.E.P. lab reports total P as ppm, chlorophyll as ug/l.

District defined a minumum standard of 15 ppb overturn phosphorus for its lakes, based on this analysis. To protect against increased loading from future land uses, the strategy for lake restoration, however, was to achieve average overturn phosphorus concentrations of 12 ppb. In 1976, the average overturn phosphorus concentrations in Annabessacook Lake, Cobbossee Lake, and Pleasant Pond were 30 ppb, 18 ppb, 21 ppb, respectively.

By using the model developed by Vollenweider and modified by Dillon and Rigler (1974), the maximum annual phosphorus loadings which could be received by the lakes without exceeding phosphorus concentrations of 15 and 12 ppb were calculated. These were then compared to the loadings estimated for 1976 to quantify needed reductions.

Phosphorus Reduction Goals

Annabessacook Lake:

The critical load (Lcrit) which would result in an in-lake concentration of 15 ppb in Annabessacook Lake was calculated as 3165 kg, based on the theoretical phosphorus retention coefficient (R) of .32, and the permissible load (Lperm) which would attain 12 ppb phosphorus was 2532 kg. The annual external phosphorus loading 1975-76 was estimated from monitoring as 3460 kilograms, and thus exceeded both of these levels. Taking into account that 300 kg of the external load in 1975-76 came from a point source which was subsequently eliminated in October 1976, a future external load would be projected as 3160 kg, approximately at the critical load but above the permissibile load of 2532 kg given by the model. The phosphorus contribution from manured fields was estimated from land use information to be 1000 kg/yr. If proper manure management could reduce this source by 50-75% as cited in the literature (Minshall et al. 1970, and Klausner and Zwerman, 1974, referenced in Annabessacook Lake Study (Sage and Moran, 1977)). the external

load would approximate the permissible load for a lake concentration of 12 ppb:

$$3160\ L_{ext} - (500 \text{ to } 750) = 2650 \text{ to } 2410 \text{ kg};$$

$$L_{perm} = 2532 \text{ kg}.$$

Without eliminating the excessive in-lake phosphorus source and restoring the phosphorus retention capacity, however, any reductions in external loading would be greatly offset by massive internal recycling. Excessive inputs of phosphorus from bottom sediments resulted in an increase in the lake concentration from 19 to 58 ppb, April to August 1976, and from 24 to 76 ppb, June to September 1977. The best prospect for immediate improvements in water quality was deemed to be elimination of internal loading by sealing off the bottom sediments, coupled with a reduction in external loading through agricultural controls.

Table 3 : Annabessacook Lake Restoration Phosphorus Reduction Goals

	L_{ext} Kg P	R (p=4.7)	In-lake P,ppb	P_{int} Kg	trophic state
Before restoration, monitored 1975-76	3460	-.32	30[1]	1800	eutrophic
Goal modeled (P_1) = 15; (P_1) = 12	3165 to 2532	.32	15, 12	a	mesotrophic
Predicted post restoration (-300kg pt. source) (-500 to 750 kg arg.) (eliminate L_{int})	2660 to 2410	.32	12.6, 11.4	not[b] significant	mesotrophic

[1] Average overturn concentration, not modeled.
[a] The lake model does not address internal loading.
[b] Zero internal loading would not be feasible unless O_2 depletion is alleviated.

Cobbossee Lake:

Three methods were used to estimate the annual phosphorus load to Cobbossee Lake: land use estimation, tributary monitoring from 1975-76, and the Dillon-Rigler model (1974), using lake concentrations measured at overturn. The three estimates were 9100 kg P/yr, 9200 P/yr, and 9400 kg P/yr.

respectively (Sage 1977a). Use of the Dillon-Rigler model yielded a critical load for Cobbossee Lake of 7843 kg/yr and a permissible load of 6274 kg/yr. Comparing these results to the estimated loading range of 9100-9400 kg, reductions of 1257 to 1557 kg (14 to 17%) in external loading would be needed to attain the critical concentration of 15 ppb, and reductions of 2826 to 3126 kg (31 to 33%) would achieve the desired concentration of 12 ppb.

Table 4 demonstrates the feasibility of restoring Cobbossee Lake through control of its two major phosphorus sources. If agricultural controls in both the Cobbossee and Annabessacook watersheds reduced those phosphorus inputs by 50%, and if in-lake treatment of Annabessacook restored the retention capacity of the sediments to .32, the phosphorus concentration in Cobbossee Lake would be well below both the 15 ppb targeted to avoid algal blooms, and the 12 ppb protection level.

Table 4 : Predicted Phosphorus Reductions in Cobbossee Lake from Restoration Techniques

	Restoration Action	Predicted[1] Pload,kg/yr	Resultant[2] [P], ppb
1.	Control of agricultural runoff in Cobbossee drainage by 50% (-1300 kg)	8100	15.5
2.	Restoration of Annabessacook L. phosphorus retention to .32 (eliminate internal loading) (-2851 kg)[3]	6549	12.5
3.	Restoration of Annabessacook L. phosphorus retention plus control of Anna. agricultural runoff by 50% (-3191 kg)[4]	6209	11.9
4.	#1 and #2 (-4151 kg)	5249	10.0
5.	#1 and #3 (-4491 kg)	4909	9.4

L_{crit} = 7843 kg; L_{perm} = 6274 kg

[1]By subtraction from the estimated load of 9400 kg/yr.
[2]From the Dillon-Rigler model using the data for A, $\bar{z}$, p. given on p.7 and R = .59.
[3]From the Dillon-Rigler model applied to Annabessacook Lake using the external loading for 1975-76 determined by monitoring, minus the Wilson Stream point source (see page 23.)
[4]As in footnote 3, except the external load is reduced by an additional 500 kg.

Pleasant Pond:

The critical load which would achieve a 15-ppb phosphorus concentration in Pleasant Pond was estimated by the Dillon-Rigler model (1974), using a phosphorus retention coefficient of .3, as 768 kg P/yr; the targeted concentration of 12 ppb would result from an annual load of 614 kg P. Using the monitored in-lake concentration of 20 ppb, the model estimated the 1976 external phosphorus load as 1024 kg. Thus, a phosphorus loading reduciton of 256 to 410 kg (25 to 40%) would be needed to achieve acceptable water quality in Pleasant Pond.

From land use analysis, the phosphorus from agricultural runoff in the watershed was estimated as 1484 kg; however, the Pleasant Pond diagnostic study (Sage, 1977b) concluded that about half of the phosphorus was removed by wetlands before reaching the pond. The single alternative of reducing the agricultural loading by 50-75% would result in 371 to 556 kg P less entering the pond, and, therefore, reduce in-lake phosphorus to desired concentrations.

Table 5: Phosphorus Reduction Goals for Pleasant Pond

Restoration Action		P-reduction kg/yr	Resulting L_{ext} kgP/yr	Resulting in-lake conc. P, ppb
Reduce agricultural phosphorus by:	50%	-371	653	12.8
	75%	-556	468	9.2

Evaluation of Restoration Alternatives

Based on the diagnostic studies, controllable sources of phosphorus for the three project lakes were identified as:

- runoff from agricultural lands
- internal recycling of phosphorus in Annabessacook Lake
- surface runoff from developed areas
- subsurface seepage from septic systems

Leachate from septic systems was shown to be a minor contributor to the lakes. Due to the high costs of sewer line extensions, and the probable secondary impacts of the resulting increased development, the Cobbossee Watershed District had encouraged the use of properly designed and maintained septic systems in its jurisdiction. Similarly, reduction of phosphorus in stormwater runoff from developed areas (9-12% of the total phosphorus loading) would not be cost-effective as it would involve expensive collection and treatment systems. The District has encouraged stormwater management planning in all proposals for new development in the Cobbossee Watershed.

Agricultural runoff contributed 78% of the phosphorus load to Pleasant Pond, and 29 and 24% of the phosphorus loading to Cobbossee Lake and Annabessacook Lake. Internal phosphorus recycling in Annabessacook Lake contributed 36% of the load to that lake, and subsequently, upstream drainage from Annabessacook Lake constituted 54% of the loading to Cobbossee Lake. Since the modeling results predicted that phosphorus concentrations below 15 ppb would be achieved in all three lakes by eliminating internal phosphorus recycling in Annabessacook Lake and reducing agricultural runoff by 50% in all three watersheds, methods for control of these two major sources were investigated.

Agricultural Control Alternatives:

Reduction of phosphorus loading from agricultural sources could be achieved with proper management of manure, primarily through the cessation of

winter spreading practices. Convincing farmers to stockpile rather than spread manure could be accomplished through two approaches:

- Financial incentive, by offering cost-sharing assistance for winter manure storage facilities;
- Regulation, requesting enforcement of Maine pollution laws prohibiting the direct or indirect discharge of animal wastes to state waters.

A survey of farmers in the three lake drainages revealed that most would have severe management problems if forced to stockpile manure without an engineered storage facility. The high cost of these facilities (from $10,000 to $40,000) had prevented their construction, as dairy farmers could not directly pass this added cost on to the consumer. A majority of farmers surveyed were interested in a cost-sharing program which would reduce their cost by 50% or more. The Clean Lakes Program was identified as a means of providing 50% cost-sharing toward these facilities. The Agricultural Stabilization and Conservation Service also could contribute up to $2500 (now $3500) for approved conservation practices. Given the farmers' interest and the availability of these federal assistance programs, the District decided to approach agricultural controls through financial incentives for voluntary compliance.

Internal Loading Reduction Alternatives:

Several techniques were reviewed as alternatives for the control of internal phosphorus recycling. (Sage and Moran. 1977). including:

- DREDGING - The sediments of concern lie in the deepest part of the lake at depths of 7 to 14 meters, and encompass approximately 150 hectares. Their removal by dredging would be prohibitively expensive, and the mixing of nutrient-rich sediments caused by dredging could only serve to increase phosphorus availability.
- SELECTIVE DISCHARGE - Immediately downstream of Annabessacook Lake is Cobbossee Lake. another large recreational lake suffering advanced eutrophication. Increased inflow of nutrient rich water from Annabessacook Lake would greatly aggravate its condition.
- LAKE BOTTOM SEALING - Use of physical lining materials would be impractical on a lake of this size.

- HYPOLIMNETIC AERATION - By maintaining well oxygenated conditions at the sediment-water interface, controlling internal recycling of phosphorus has been achieved in some lakes. However, Annabessacook Lake's size again renders this alternative questionable. To adequately aerate a basin 150 ha in area with depths of 7-14 meters would require several large pumps running continuously. The long term operation and maintenance costs would be considerable. In addition, the continuous noise of the compressors would be objectionable to most lakeshore residents.

- NUTRIENT INACTIVATION - Nutrient inactivation involves chemically treating a lake with agents which absorb or chemically bond to soluble phosphorus and remove it from the water column through precipitation. Researchers have investigated several inactivation agents, including zirconium and lanthanum rare earth elements, fly ash, iron, calcium and aluminum. However, all of these except aluminum were judged to have serious limitations due to toxicity effects or incompatibility with the pH levels found in Annabessacook Lake bottom waters. Aluminum appeared most likely to (1) effectively remove phosphorus under conditions found in the Lake; (2) retain phosphorus in the sediments following precipitation ; (3) produce little adverse effect on aquatic life, and, (4) be effective within the financial limits of the District.

After a review of these, only nutrient inactivation appeared feasible and practical.

6. AGRICULTURAL WASTE MANAGEMENT PROGRAM

PROGRAM DEVELOPMENT

Problem Identification

The diagnostic studies conducted on Jock Stream in 1975-76 clearly demonstrated that agricultural runoff, particularly in the winter months, was a significant source of phosphorus to the lakes. At the onset of the project, a detailed survey of individual farms, together with a literature review of factors contributing to phosphorus export from agricultural lands, served to focus the strategy for controls. These investigations revealed the following:

- One dairy cow produced wastes which have the phosphorus equivalent of 16 humans. Comparing animals to humans in the three restoration lake drainages:

	# Humans	# Livestock Human-equiv.
Annabessacook Lake	7,000	5,350
Cobbossee Lake	3,000	10,200
Pleasant Pond	3,000	8,400

- Runoff from fields receiving winter manure applications showed phosphorus concentrations as high as 20,000 parts per billion (concentrated snowmelt, no rain) and typically as high as 5,000 ppb during periods of rain and snowmelt at flows approximating .18 m^3/s. Phosphorus concentrations in excess of 15 ppb in the lakes are believed to trigger nuisance algae blooms.

- Two practices of concern as secondary contributors to agricultural pollution were identified after a detailed survey of farms in the project area:
  - barnyards located in close proximity to waterways or road ditches; and
  - manure stockpiles located near or in waterways and drainage ditches.

Identifying Solutions

The objective of the agricultural waste management program was to reduce agricultural phosphorus runoff in the drainages of the three project lakes by providing cost-sharing grants for the construciton of manure storage systems and runoff controls. The primary goal was storage of manure accumulations during the winter months. In Maine, a minimum of six months storage capacity is required to avoid spreading on frozen or snow-covered ground.

The design of manure storage systems is complex and solutions differ on every farm. A manure storage "system" is composed of three basic elements:

- a containment structure: this may range from a simple concrete or asphalt pad surrounded by earth berms, to a concrete walled - building, with or without a roof;
- a transfer system to get the manure from the barn to the storage structure: these include paddle-chain conveyers, manure blowers, or underground hydraulic ram pumps; when manure is semi-solid or liquid, it is scraped out of the barn with a tractor and blade into a storage, or into a pump which pushes the manure to the storage structure.
- a removal and application system to get the manure out of the containment and onto the land: when manure is solid or semi-solid this entails use of a tractor and bucket, and spreader equipped with a hydraulic end gate if semi-solid; liquid systems must have agitator and evacuator pumps and liquid tank spreaders which spray the manure on the land.

For most farms, winter storage of manure meant a drastic change in the entire manure handling system. One reason for this is Maine's relatively short growing season. Farmers must have their land fertilized and crops planted by early June. Often ground conditions prohibit use of heavy equipment until May, leaving only a matter of weeks to perform these critical tasks. An efficient manure handling system, given these constraints, is essential. In most cases this would involve new or additional handling equipment and transfer systems, particularly if the consistency of the manure was changed from solid to liquid as a result of storage.

In addition to winter storage of manure, the project aimed to reduce agricultural phosphorus runoff from barnyard runoff by constructing diversions, asphalting heavily trafficked areas, providing roof gutters, and installing filter strips. Other practices such as removal of abandoned manure piles, collection and storage of milkroom waste water, and use of buffer strips near waterways and streams were identified as means to further reduce agricultural pollution.

Coordinating a Multi-Agency Effort

To assist farmers in making the changes needed on their farms, the Cobbossee Watershed Lakes Restoration Project brought together a number of agencies which had allied interests in furthering good farm management practices. The Project provided a common focus, water quality protection, for the coordinated effort which included financial assistance agencies: U.S. Environmental Protection Agency (EPA), U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service (ASCS) and Farmers Home Administration (FmHA); and technical assistance agencies: Cobbossee Watershed District (CWD), U.S. Soil Conservation Service (SCS), Kennebec County Soil and Water Conservation District (KCSWCD), and the University of Maine Cooperative Extension Service.

Coordination of these various agencies revolved around a series of functions which reflect the complexity of the program:

- Development of a cost-sharing program which coordinated two federal programs administered by two separate agencies - the U.S. EPA and USDA.
- Contacting the farmers to explain the purposes of the project; procedures for obtaining cost-sharing and financing; and availability of technical assistance.
- Development of farm management plans including design of structural controls needed to reduce pollution; stipulation of rates and timing of manure applications to land; and description of buffer zones adjacent to streams.
- Securing the cooperation and participation of the farmers.
- Assistance to contractors in understanding and meeting construction specifications.
- Assistance to farmers in soliciting bids and obtaining contractors and materials for the construction of needed practices.
- Inspection of construction projects to ensure compliance with specifications.
- Interpreting state and federal tax law to assist farmers in obtaining available tax refunds and exemptions, and meeting tax liabilities for grant monies received.
- Surveillance of farm management practices following installation of controls to detect problems or failure to comply with manure spreading restrictions.

Developing a Cost-Share Program

The Cobbossee Watershed District had determined through its 208 studies that a financial assistance program was a prerequisite for achieving reduction of agricultural pollution to its lakes. The Restoration Project coordinated two federal cost-sharing programs to assist farmers with the high cost of pollution control measures.

Through the long standing federal Agricultural Conservation Program (ACP), the ASCS could offer farmers a maximum of $2,500. towards a practice. In 1979 this limit was raised to $3,500. This alone had not been sufficient assistance to enable farmers to construct needed manure storage facilities and other pollution control practices. However, when this program was combined with 50% cost-sharing available through the EPA Section 314 Clean Lakes Program, the resulting financial assistance package became significant, and attracted the immediate interest of most farmers in the watershed.

A memo of understanding was signed between the District and local ASCS offices in two counties. It was agreed that the ASCS and District cost share programs would be administered separately, but coordinated as follows:

The Cobbossee Watershed District would:

- Recommend priority farms for ACP cost-sharing to control water pollution problems and designate farms participating in the District's Lakes Restoration Program.
- Consult with ASCS/USDA on administrative and procedural matters relating to cost-sharing of conservation practices.
- Notify ASCS/USDA of payments to farmers under the District Lakes Restoration Program.

The Agricultural Stabilization and Conservation Service would:

- Receive and process applications and requests for ACP assistance from farmers located within the designated project area for pollution abatement practices.
- Issue ACP funds upon notification from the Watershed District that it had completed its cost-sharing for an individual farm project.

The ASCS county committees added considerable support to the project, giving the participating farmers top priority for funding. The State ASCS committee reinforced this support by allocating additional funds to the county offices to assure maximum availability of cost-share monies.

Developing Animal Waste Management Plans

Developing animal waste management plans which would meet the pollution control objectives of the Watershed District, as well as the management and financial constraints of the farmers was one of the most challenging aspects of the project.

Farmers had long received technical assistance in planning and implementing farm improvements through their county Soil and Water Conservation Districts and their service agencies, the U.S. Soil Conservation Service and the Cooperative Extension Service. The focus of this assistance, however, had been primarily farm productivity, not pollution control. On the other hand, the Cobbossee Watershed District, created as a water resources management agency, had little familiarity with farm planning. The Restoration Project combined the expertise of the existing agricultural assistance agencies and the Cobbossee Watershed District in a cooperative effort.

Management plans were prepared for each cooperating farmer, by the SCS Conservationist, specifying animal waste management procedures and other measures required to reduce sediment and phosphorus runoff to tolerable limits. The plans, signed by the farmers, Conservation District, and Watershed District, generally contained the following:

(1.) A map of the farm, plotted on recent SCS soils maps.

(2.) An assessment of manure storage needs and recommended storage and handling facilities.

(3.) Recommended runoff control measures.

(4.) Operation and maintenance requirements for all structural facilities.

(5.) A manure disposal plan specifying maximum allowable application rates and methods by field, based on soils information and water quality considerations, with qualifications as needed for timing of the disposal, distance from drainageways and water bodies, etc.

(6.) A plan for supplementing animal manures with chemical fertilizer if needed, specifying application rates by field and qualified according to limitations in distance from waterbodies and drainageways, timing of application, etc.

(7.) Recommendations for improving livestock grazing areas, including exclusion from waterways and provision of alternate watering facilities if appropriate.

(8.) An implementation schedule for all recommended practices.

In the design of structural controls the Soil Conservation Service provided standard engineering designs for diversions, earthen lagoons and concrete containment structures. These were modified by the Cobbossee Watershed District for pollution control. Staff from the Watershed District and the Kennebec County Soil and Water Conservation District then worked intensively with the farmers in preparing alternative plans for manure handling and runoff controls. Once a plan was selected, the Soil Conservation Service engineers reviewed and certified all structural controls. Farmers were also given the option of furnishing their own designs, provided they were certified by a registered Engineer.

One interesting aspect related to the design of structural controls was the introduction of new technologies during the course of the project. In the second year, a pre-cast concrete containment was developed by a private firm as an alternative to high cost poured-in-place structures. Other technological improvements grew out of the experience gained in the operation of various systems in the extreme Maine climate, and in response to rapidly escalating fuel costs. New devices for transferring manure from the barn to the storage included a fan-like apparatus which distributes solid manure in a stacking facility, and gravity flow systems which totally eliminate mechanical systems for transferring manure to and removing it from the storage facility. Keeping abreast of these and other innovations was important in order to avoid investment in a system which could

quickly become obsolete in a time of rapidly changing technologies.

Securing Farmer Participation

Convincing the farmers to participate in the program was a task of crucial importance. The farmer's share of costs ranged from $500., for small scale poultry manure stacking sites to $20,000. for some large-scale dairy farms. Over half of the dairy farmers faced a minimum investment of their own funds of $5,000., and a third were asked to invest in excess of $10,000. Consequently, it was necessary to demonstrate to the farmers not only the pollution control benefits, but also the benefits to farm productivity and farm management.

A number of means were employed to assist the farmers in examining the costs and benefits of alternative manure management systems, as well as determining how best to finance their share of the project cost. A series of fact sheets, entitled "Manure Management Notes," were prepared which detailed information on the program requirements, pollution control loans available through the Farmers Home Administration and the Small Business Association, federal and state tax incentives and liabilities, and existing manure storage systems in central Maine.

In addition, each year the Kennebec County Soil and Water Conservation Commission sponsored a bus tour of systems built under the project and through other programs. This allowed farmers to benefit from the experience of Maine farmers in the operation and maintenance of new manure storage and transfer facilities. Prior to the project, only a handful of such systems existed in the state.

Slide shows provided another means of information and education. As part of the annual conservation tour described above, and at the Conservation District's annual meeting, slide shows assembled by the Watershed District depicted the progress achieved and demonstrated the variety of systems being installed.

Other informational mechanisms included periodic updates in the Conservation District newsletter, educational materials available through the Cooperative Extension Service, media coverage by local newspapers, and features in the Conservation District and Watershed District annual reports.

Generally, the success of the project in securing the participation of the farmers in the project area hinged on the ability of the Watershed District and the Soil and Water Conservation District to design systems that would substantially increase efficiency and convenience on the farms. Given the range of options available, this necessitated producing from 3 to 5 detailed plans per farm, a time consuming process. As a result, the project required an extension from its original 30 months to 48 months in order to give the farmers the opportunity to carefully consider all options before making a final decision.

Facilitating the Construction Process

Because EPA regulations required that the procurement of supplies and construction services be based on a competitive selection process, farmers were instructed to obtain at least three price quotations for all major cost components of their projects. Specifically, these included concrete, reinforcing steel, roof materials, gravel or fill, labor for concrete work, carpentry labor, and equipment. In addition, if any single cost component exceeded $10,000., a formal bid procedure requiring advertising, sealed bids, binding contracts, etc., was mandated.

As a result of the added administrative requirements and increased lead time needed for the formal bid procedure, it was in the interest of the farmers to act as their own general contractor in order to keep all transactions below the $10,000. limit. This meant securing materials and services directly from a variety of contractors rather than hiring a single contractor to coordinate the project.

The Soil Conservation Service, Kennebec County Soil and Water Conservation District and the Cobbossee Watershed District assisted the farmers in this effort. The Soil Conservation Service provided blueprints and specifications for construction work. The Conservation District advertised in the local papers for qualifications and statements of experience from all contractors interested in performing work on manure storage facilities, and from the responses assembled a list of interested contractors for the farmers. The Watershed District and Conservation District also held a meeting for interested contractors to explain the project requirements, construction specifications and inspection procedures which would affect their performance on a job. Staff from the two Districts also assisted the farmers directly in obtaining price quotations from contractors. Finally, the Watershed District prepared a standard contract which farmers could use if desired in the procurement of major services. Only one farmer opted to follow this approach.

Once construction was scheduled for a farm, the Conservation District and Watershed District staff assisted the site work contractors in determining the lines and grades needed for the drainage and foundation work. The staff also provided inspection services to assure proper placement of steel and adherence to specifications on the quality and placement of concrete.

Monitoring Operation and Maintenance

To assist farmers with any problems which could arise in use of manure storage facilities, and to assure their proper maintenance and operation, the Watershed District conducted periodic field checks of participating farms. In so doing, the District found that some systems needed modification due to unexpected problems. For example, on one farm a change in feed program caused a change in manure consistency and manageability so that a "stacking facility" became inadequate

In another, drainage problems associated with a runoff collection basin necessitated installation of a major diversion in the following year. In still another case, a facility designed without a roof did not operate to the satisfaction of the farmer, and a roof was added the following summer. It is important to note that in some cases the farmers would not have taken the initiative to correct the problem without encouragement from the District.

Field checks also revealed that some farmers were slow to give up old habits despite having built a storage facility. In some cases, if the ground was bare of snow, as it was during most of the 1979-80 winter, the farmer assumed it was acceptable to spread manure. Similarly, if the ground was bare of snow until mid-December, as it frequently is in Maine, some farmers continued to dispose of manure on their fields. The logic of storing manure during frozen ground conditions was not as apparent as storing when the ground was snowcovered. Upon contacting the farmers to discuss this problem, the District found them generally willing to cease spreading at the onset of frozen conditions in the future.

PROGRAM ACCOMPLISHMENTS

Participation

By the end of the project period, 23 livestock and dairy manure storages, 9 poultry manure storages, and several barnyard runoff controls had been constructed. This represented participation of 75 percent of the farms which together had accounted for 78 percent of the livestock waste and 60 percent of the poultry waste generated and used within the project area.

Table 6 details participation of livestock farmers and their relative phsophorus significance by lake drainage. Table 7 shows participation of poultry farmers. In general, poultry farmers do not represent the same type of pollution threat as dairy farmers because of differing manure management practices. Thus, relative significance is indicated only as the percent of phosphorus generated by poultry farms and disposed of or used in the watershed.

Table 6 Farmer Participation and Relative Phosphorus Significance (Livestock Farms, 1978-1981)

ANNABESSACOOK LAKE DRAINAGE

Farmer	no. animals	Phosphorus Generated human equivalents	Kg	% in drainage	Controls Built 1978	1979	1980	1981
Participants								
1	90	1440	2160	27	x			
2	55	880	1320	17		x		
3	110	1760	2640	33	x			
	(255)	(4080)	(6120)	(77)				
Nonparticipants								
4	40	640	960	12				
5	35	560	840	11				
	(75)	(1200)	(1800)	(23)				
Totals	330	6720	7920	100				

COBBOSSEE LAKE DRAINAGE

Farmer		no. animals	Phosphorus Generated human equivalents	Kg	% in drainage	Controls Built 1978	1979	1980	1981
Participants									
1		38	608	912	6		x		
2		87	1392	2088	13	x			
3	(pigs)	275	395	593	4	x			
4		33	528	792	5				x
5		68	1088	1632	10	x			
6		100	1600	2400	14			x	
7		75	1200	1800	11			x	
8		100	1600	2400	14			x	
9	(pigs)	366	659	989	6		x		
		(1142)	(9070)	(13606)	(83)				
Nonparticipants									
10		20	320	480	3				
11		100	1600	2400	14				
		(120)	(1920)	(2880)	(17)				
Totals		1262	10990	16486	100				

PLEASANT POND DRAINAGE

Farmer	no. animals	Phosphorus Generated human equivalent	Kg	% in drainage	Controls Built 1978	1979	1980	1981
Participants								
1	60	960	1440	10		x		
2	18	288	432	3		x		
3	20	320	480	4	x			
4	35	560	840	6	x			
5	65	1040	1560	11				x
6	25	400	600	4	x			
7	45	720	1080	8	x			
8	20	320	480	4	x			
9	30	480	720	5	x			
10	105	1680	2520	18		x		
	(423)	(6768)	(10152)	(73)				
Nonparticipants								
11	40	640	960	7				
12	55	880	1320	9				
13	40	640	960	7				
14	22	352	528	4				
	(157)	(2512)	(3768)	(27)				
Totals	580	9280	13920	100				

Table 7: Participation of Poultry Farmers 1978 - 1981

Farmer Drainage	No. Birds	% P Generated and Used in Drainage	Controls Needed	Year of Construction
ANNABESSACOOK L.				
1	43,000	43	Yes	1978
2	48,000	57	No	--
3	40,000	0	No	--
4	20,000	0	No	--
COBBOSSEE L.				
1	58,000	30	Yes	1978, 79*
2	6,000	3	Yes	1978
3	7,600	4	Yes	--
4	62,500	32	Yes	--
5	60,000	31	Yes	--
6	35,000	0	No	--
PLEASANT P.				
1	42,000	15	Yes	1979
2	20,000	7	Yes	1978,79
3	43.000	16	Yes	1979
4	30,000	11	Yes	1978
5	21,000	8	No	--
6	31,000	11	No	--
7	82,000	0	No	--

Project Costs and Benefits

The total cost of the agricultural waste management program was approximately $610,000 for construction of manure storage facilities and runoff controls. Additional costs were incurred for project administration and technical assistance, and for an intensive water quality monitoring project of a small agricultural subdrainage of Cobbossee Lake, conducted to assess the effectiveness of the agricultural controls in improving water quality. Not included in these figures is the cost of assistance from the U.S. Agricultural Stabilization and Conservation Service, which actively participated in the project under their regular program funding, and the technical services of the U.S. Soil Conservation Service, the Cooperation Extension Service, and the county Soil & Water Conservation Districts.

Costs for individual farm projects varied considerably according to the type of farm (dairy, poultry, swine,etc.), size of operation (20-100 cow dairy farms, 6,000-60,000 broiler farms), farm management requirements, and site characteristics. Consequently, costs ranged from $6,000 for a simple concrete pad-earth bermed field stacking facility for 3 months' storage of poultry litter, to $60,000 for a 7-month liquid storage system for manure and milkroom waste generated by a 100-cow dairy farm (including liquid handling transfer and application equipment). Table 8 presents 4 typical project cost summaries.

Costs for dairy manure storage systems, translated to dollars per animal unit (1200-pound cow), average $275 for a bermed stacking pad (180-day capacity); $500 for a roofed concrete box stacking facility, (180-day capacity); and $600 for a subgrade concrete liquid manure - milkroom storage system (220-day capacity). These figures include all construction costs, including costs of barn modifications, gutter cleaner system changes, transfer systems, but not equipment for field application (except for the liquid system).

While the agricultural controls program provides public benefits of improved water quality, the farmers also benefit from more efficient manure management systems which save labor, fuel and equipment costs while conserving the nutrient

Table 8 TYPICAL MANURE STORAGE FACILITIES AND COSTS

TYPE FARM	MANURE SYSTEM COMPONENTS	TOTAL COST
DAIRY		
90 milkers	50' x 80' x 10'	
20 youngstock	Concrete Storage	25,700.
freestall	with push-off ramps	2,000.
	and roof	9,200.
	Equipment	3,100.
		$40,000.
DAIRY		
28 milkers	40' x 40'	
20 youngstock	Asphalt Pad with	1,200.
stanchion	8' Concrete headwall	6,400.
	and earth sides	1,800.
	Equipment	4,400.
		$13,800.
DAIRY REPLACEMENTS		
20 animals	37' x 37' x 4'	
stanchion	Concrete storage	4,850.
	Asphalted barnyard	2,100.
	Runoff controls	
	holding basin	450.
	450' diversion	1,500.
		$8,900.
POULTRY LITTER STACKING SITE		
Broilers, 20,000	40' x 40'	
	Concrete Pad	2,900.
	with earth berms	3,100.
		$6,000.

Table 9

Cost-Benefit Summary of 5 Hypothetical

Manure Management Systems*

Farm/Management Description	Deprec. + Annual Fixed Costs	Annual Operating Costs	Value of Manure	Adjusted Annual Cost	Annual Cost/ a.u.
I. 70 a.u. stanchion farm-daily hauling	1,373	4,769	4,003	2,139	30.55
II. 70 a.u. stanchion farm-stacking manure 180 days in a roofed concrete pit	2,375	2,327	4,380	322	4.60
III. 90 a.u. free stall farm-daily hauling	1,378	6,955	5,718	2,615	29.05
IV. 90 a.u. free stall farm, 180 day concrete manure storage with roof	2,904	4,578	6.257	1,225	13.60
V. 90 a.u. free stall farm, 365 day storage for manure & milkroom waste in earthen basin	2,552	5,416	6,682	1,286	15.30

* Does not include intangible benefits such as increased convenience for the farmers, or public benefits accrued from improved water quality.

value of manure for crop production. With cost-sharing available to cut the high investment costs, farmers should save from $15 to $30 per animal unit per year by abandoning the practice of daily hauling and spreading during the winter months. (see Table 9). These savings should allow recovery of the initial capital investment in 10-20 years. At the same time, the convenience of the system alone was sufficient benefit to pursuade most farmers to make the necessary investment.

SPECIAL PROBLEMS AND CONSIDERATIONS

The Cobbossee Watershed District's Lake Restoration Project represented an innovative approach to water quality management. While at least one other Clean Lakes project had focused on control of agricultural phosphorus sources by matching EPA and State funding resources, the Watershed District's project was the first to propose matching a substantial monetary committment by the farmers with EPA grant funds to achieve the same goals. In addition, it was the first such project to be conceived, administered and coordinated by a non-agricultural local unit of government. The success of the project hinged on the District's ability to provide a common focus for a concerted effort by a half dozen previously unrelated local, state, and federal agencies -- assisting and encouraging farmers to take advantage of a unique opportunity to improve farm management while benefiting water quality. This complex project produced a number of problems and obstacles, which had to be overcome for successful implementation.

Underestimating the Scope of Effort

One of the most significant problems encountered in the project was an underestimation of the time and effort required for planning and building 31 manure storage systems. Initially the project had anticipated that all farm projects could be completed by the end of 1978, a year and a half following its initiation. Based on this assumption, the project budgeted funds for its

agricultural coordinator for this 18-month period. When it was realized that substantially more time would be needed to successfully complete the agricultural controls component of the project. the District was caught without sufficient funds to provide needed staffing.

A number of factors contributed to extending the project beyond the original estimates. Most importantly, neither the Soil Conservation Service nor the Watershed District comprehended the degree of effort required to convince farmers to participate and to design suitable systems for individual farms. The SCS had worked with only a handful of farmers on manure storage systems prior to the project, and in each case, the farmer had already decided that a system was to his or her advantage. In addition, the farmer had usually selected the general type of system to be installed. These decisions may have been years in the making. Consequently, when SCS became involved, what remained to be accomplished were the relatively straightforward tasks of working out the details, providing drawings and specifications, and scheduling the construction.

When the Cobbossee Watershed District project commenced in August of 1977, few farmers in the project area had given much thought to a manure management system, and some would not even acknowledge that their farms could cause a pollution problem. Instead of the farmer approaching SCS, ready and willing to proceed with a project, the SCS had to approach the farmer and convince him/her that a system was needed, not only for water quality improvement but also for improved farm management, and that such a system was worth a substantial financial committment. Having persuaded the farmer on these points, the task of designing an appropriate system remained. This usually involved developing designs and cost estimates for 3 to 5 alternatives before the farmer would decide what best suited his needs and financial limitations. Thus the process of convincing 31 farmers to participate and providing the technical assistance needed by each

to select a system responsive to both water quality and farm management needs was time-consuming beyond expectations.

Overcoming Bureaucratic Impediments

A series of other problems caused delays in the design or construction process or hesitation by farmers to make a definitive committment to the project. Insufficient assistance from SCS during the first year of the project was among the most serious of these problems.

At the onset of the project, the SCS District Conservationist for Kennebec County was removed from the Lakes Project and assigned to work with the Maine Department of Agriculture for two years. His replacement, not familiar with the project, worked on conservation practices elsewhere in Kennebec County, leaving the task of servicing the 31 farmers in the Lakes Protection area to the Kennebec County Soil and Water Conservation District technician, and the Watershed District agricultural coordinator. As mentioned previously, the Watershed District had funded its agricultural coordinator only through January 1979. The Conservation District technician was also funded for a limited time, until December 1978. Although 16 projects were completed or initiated in that first year, a substantial number of farms remained which had to delay participation until 1979.

From January 1979 to the end of the project, SCS assumed increased technical responsibility for the project, assisted by two CETA employees at the Conservation District. This change in personnel may have contributed to the fact that the remaining 14 projects took three years to complete. Projects contemplating the use of non-reimbursed agency assistance in the future should consider signed cooperative agreements to assure a mutual understanding of agency roles and responsibilities.

Another problem which caused delays in projects was passage of the "Culver Act" early in 1978, which established the Rural Clean Water Program. This created a program within the U.S. Department of Agriculture to fund agricultural pollution control projects at a rate of 50% and higher in some cases. Although proposed

appropriations were quite limited and unlikely to be allocated to the Cobbossee Watershed, many farmers decided to wait for a "better deal" than the Lakes Restoration Project. This attitude was stimulated in part by statements from the SCS State Conservationist in attempts to gail local support in securing RCWP funds for Maine. After the Cobbossee Watershed District expressed its concern to SCS about the implications of these raised hopes, the State Conservationist wrote to area farmers urging their participation in the Lakes Restoration Project.

Unanticipated delays were also encountered by farmers attempting to secure loans from Farmers Home Administration to meet their share of the project costs. These delays were caused by shortages in available funds and a cumbersome system of processing applications. In one case, 10 months elapsed between the filing of the application and the securing of funds, forcing construction to begin in November when weather conditions increased costs. Future projects should expect to encounter similar delays due to limited loan funds and increasing competition for them.

Ensuring Adequate Participation

Overcoming the resistance and often negative attitudes of some farmers represented another challenge to the District. The program initially intended to solicit voluntary participation on the assumption that financial limitations, not attitudes, had prevented farmers from taking corrective actions on their own. This was in large part confirmed by the number of farmers who willingly participated. A small minority, however, seemed financially capable but unwilling to meet their responsibility. Unfortunately, a few in this minority were also major contributors to lake pollution. Without their participation, the effectiveness of the controls built by other cooperating farmers would be jeopardized.

In the spring of 1979, the Cobbossee Watershed District Board of Trustees adopted a policy to exert pressure on nonparticipating farmers through regulatory

means. Under Maine law, agricultural wastes of any kind may not be discharged directly or indirectly to Maine waters without first obtaining a license from the Board of Environmental Protection. Violators may be forced to pay fines and cease discharges. The Watershed District trustees decided to coerce the reluctant farmers to at least stop the practice of winter manure spreading by suggesting that the District might be forced to issue a complaint to the Maine Department of Environmental Protection (DEP). Several farmers responded positively by enlisting in the program. Those who failed to respond were referred to the DEP for investigation. These investigations prompted the remaining farmers to either participate in the program, or alter disposal practices to reduce pollution. A total of 5 farmers were added to the list of participants as a result of these efforts.

Deciding to pursue a regulatory approach, thereby deviating from the original intent of the project, was a difficult decision for the Watershed District Board of Trustees. After a lengthy debate, the Board concluded that it had an obligation to ensure that the project would not be jeopardized by farmers who were capable but unwilling to alter practices harmful to water quality.

The decision met stiff opposition by the Kennebec County Soil and Water Conservation District Supervisors, who were cooperators in the project. They disagreed with a regulatory approach, on the basis that through their close affiliation with the project, their good working relations with their farmer constituents would be damaged. However, after a brief period of resistance and objection by the farmers affected, the problem was quickly resolved. Most farmers decided to utilize the opportunity and entered the program. No legal action was taken against any farmers.

7. ANNABESSACOOK LAKE ALUM TREATMENT

This section has been largely adapted from a paper by David R. Dominie II, entitled "Hypolimnetic Aluminum Treatment of Softwater Annabessacook Lake", presented at the International Symposium of Inland Waters and Lake Restoration, September 8-12, 1980, Portland, Maine.

FEASIBILITY

Internal Nutrient Loading

The goal of the in-lake restoration phase was to mitigate internal nutrient loading so that natural recovery of the lake resulting from reduced external loading might be accelerated. Internal loading occurs from both oxygenated and anoxic bottom sediment. (Lee. et al. 1977). Phosphorus release rates are generally far greater in anoxic sediment, but such conditions are generally confined to hypolimnetic sediment. Low vertical diffusion rates in the metalimnion can severely restrict phosphorus movement from the hypolimnion into the epilimnion, thereby limiting its availability for algal assimilation (Schindler, Hesslein, and Kipphut, 1976; Sweers, 1970). However, significant nutrient transfer can occur in lakes which experience a metalimnetic phosphorus buildup, and are also subject to such phenomena as thermocline migration and/or internal seiches (Stauffer and Lee. 1974; Mortimer. 1971).

Phosphorus from oxygenated epilimnetic sediment, though less rapidly released, is more immediately available for primary production than hypolimnetic released phosphorus, and can be a significant internal source. In smaller lakes, where the littoral zones comprise a relatively large portion of the lake area, littoral inputs may be particularly important, especially where inputs are enhanced by groundwater inflow and macrophyte pumping (Twilley, et al. 1977;

McRoy, et al. 1972). Conversely, in larger eutrophic lakes, seasonal nutrient inputs from the hypolimnion may dominate. In most lakes it is likely that a number of internal sources contribute nutrients, at least on a seasonal basis.

Annabessacook Lake has both a large anaerobic hypolimnion and a macrophyte-covered littoral zone. The lake annually shows a large phosphorus buildup concurrent with the loss of oxygen in the hypolimnion. This buildup extends into the thermocline by mid-summer at which time it is likely that considerable transfer to the epilimnion occurs. Also the lake has historically experienced fall blooms that correspond with fall overturn when the nutrient-enriched bottom waters become incorporated in the rest of the lake. It was felt that if hypolimnion P was made unavailable, fall blooms might be less severe. The reduction of any phosphorus transferred out of the hypolimnion to the littoral zone during overturn might mean that this phosphorus would not be available through some form of littoral release at a future date.

Alum Literature Review and Laboratory Studies

Preliminary studies and laboratory tests were conducted to determine if aluminum compounds could effectively tie up phosphorus in Annabessacook water without causing adverse ecological impacts. A review of the literature showed that aluminum compounds effectively remove dissolved phosphorus and particulate matter from lake water, and that the settled floc retards phosphorus release from bottom sediments. Peterson (1977) and Browman, et al. (1973) found that aluminum is most effective in removing phosphorus from water when the phosphorus is in the inorganic form. Conditions which favor a high inorganic P to organic P ratio are therefore more likely to respond to aluminum treatment. Peterson (1977) also found that phosphorus

release from bottom sediments in dimictic lakes remained suppressed several years after treatment with aluminum. Cooke, et al. (1978). and Kennedy (1977), obtained similar results in both Dollar and West Twin Lakes. Where the control of phosphorus release from bottom sediments is an objective, these investigators advocate using a maximum aluminum dosage. They define maximum dose as that dose above which the dissolved aluminum concentration exceeds 50 ug Al/1, a concentration found by Everhart and Freeman (1973) to be safe for rainbow trout.

Filter alum (Al_2SO_4 $14H_2O$), the most commonly used inactivating agent. destroys 0.5 mg/1 of alkalinity for every 1 mg/1 of Al (Sawyer and McCarthy, 1967). When alum is used in low alkalinity lakes such as Annabessacook (15 to 20 mg/1 alkalinity as $CaCO_3$) a balancing alkaline compound must be used. An effective means of obtaining this balance is with sodium aluminate ($Na_2Al_2SO4xH_2O$), a high alkalinity compound that offers the advantage of additional aluminum as well as buffering capacity.

To determine the specific responses of aluminum in Annabessacook water, a series of lab tests were run. Table 10 shows the results of the alum/aluminate ratio testing. Ratios yielding solutions with pH's in the 6 to 7 range had "dissolved" (.45u filtered) aluminum levels below the detection limit of .08 mg Al/1. At pH's outside this range, dissolved Al concentrations rose to potentially toxic levels. As a result of these tests and others, a volumetric alum/aluminate application ratio of 1:1.6 was chosen.

Another set of tests was used to determine the efficacy of P removal by Al^{3+} over a range of Al^{3+} and P concentrations. Table 11 shows inorganic phosphorus removal exceeded 98 percent for all aluminum dosages.

Table 10. Alum-aluminate ratio testing.

Sample	Initial Aluminum (mg/l)	Alum: Aluminate Volumetric ratio	pH	Residual Aluminum (mg/l) .45u filtered
A1	50	1:1	4.5	15
A2	50	1:1.8	5.1 - 5.2	BDL*
A3	50	1:3	8.0 - 8.2	.24 - .47
B1	20	1:1	4.8	1.5 - 1.6
B2	20	1:1.8	6.2 - 6.4	BDL
B3	20	1:3	7.8 - 8.0	.25 - .40
C1	10	1:1	5.2 - 5.3	.09 - .17
C2	10	1:1.8	6.4	BDL
C3	10	1:3	7.1 - 7.2	BDL

*BDL - below detection limit

Table 11. Phosphorus removal alum aluminate ratio 1:1.6.

Aluminum (mg/l)	Initial P (ug/l)	Final P (ug/L) .45u filtered	pH
50	500	2	6.4 - 6.6
50	1000	2	6.5
20	500	2	6.5 - 6.6
20	1000	2	6.5 - 6.8
10	500	2	6.5 - 6.7
10	1000	2	6.6 - 6.7
5	500	2	6.5 - 6.8
5	1000	5-6	.67 - 6.8

In addition to chemical tests, bioassays using fish and macroinvertebrates as test organisms were run in an attempt to identify potential toxicity resulting from aluminum application. Chironomus plumosus, one of

only two benthic species found in the Annabessacook hypolimnion during summer months, was placed in 500 milliliter flasks containing anoxic lake water and 2.5 centimeters of bottom sediment. Aluminum compounds were added on a sediment areal basis in proportion to the maximum dosage anticipated for the project. This amount of aluminum (70,000 mg Al/m^2) formed a thick layer of white floc in the test containers. The flasks were viewed daily, and the test organisms were observed to be lying on the floc, and moving through it as they might through any natural flocculant substrate. Mortality increased with test duration, exceeding 50 percent by day 30. In all cases, however, the controls displayed higher mortality than the test flasks (Table 12).

Table 12 Macroinvertebrate bioassay (*Chironomus plumosus*).

Time	DO	pH	Alka-linity	Temp (°C)	No. Alive	No. Dead	Survival %
0	0.6	6.7	62	9.0			
4 day:							
test	0.2-0.8	5.0	8	9.0	24	1	96
control	0.2-0.3	6.7	65	9.0	15	2	88
15 day:							
test	0.4-0.5	5.8	16	9.0	13	11	54
control	0.2-0.4	7.0	79	9.0	7	7	
30 day:							
test	0.2	5.9	14	9.0	10	13	43
control	0.2-0.4	6.5	78	9.0	2	7	22

In addition to the macroinvertebrate tests, 96-hour static bioassays using golden shiners (Notemigonus crysoleucus, a lake inhabitant), were conducted. The tests were carried out in 1-gallon glass jars, each containing two fish in 3 liters of lake water. Test results (Table 13) show no mortality over the entire range of aluminum concentrations. The fish did not appear to be stressed by the test conditions, nor did they avoid the aluminum floc even in the 100 mg Al/l jars.

These tests indicated that by careful manipulation of alum/aluminate ratios and dosages, phosphorus can be effectively removed from lake water. At the same time pH levels could be held within an acceptable range to minimize potential toxicity problems.

Table 13. - 96-hour static bioassay (Notemigonous crysoleucas).

Aluminum (mg/l)	pH (0-hour)	pH (96-hour)	% Survival at 96 hours
0	6.8	6.9 - 7.0	100
1	6.7 - 6.9	6.9 - 7.0	100
10	6.9 - 7.0	7.0 - 7.1	100
100	7.1	7.0 - 7.1	100

Conclusion

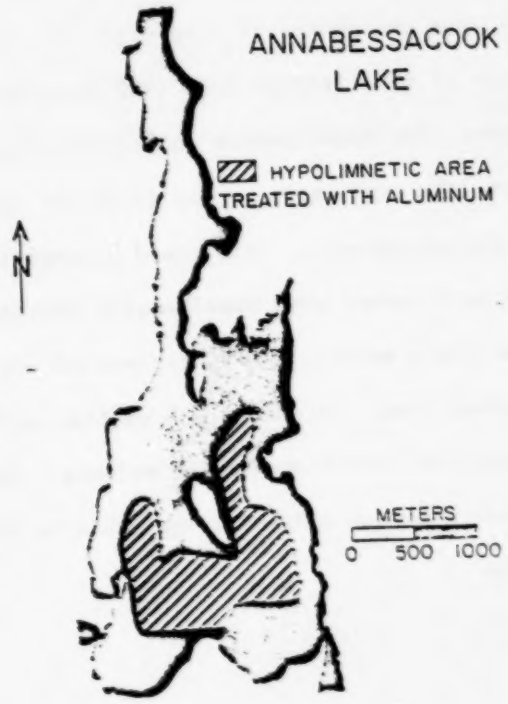
It was decided that a hypolimnetic aluminum application, covering the entire area of anaerobic sediment, would be most appropriate for Annabessacook. Although littoral zone phosphorus release might be significant in Annabessacook Lake, the vast size of the littoral zone (400 hectares) presented enormous logistical problems. The hypolimnetic application would accomplish two objectives. First, the application would strip the hypolimnion of phosphorus by precipitation and entrapment. This could be expected to be most effective if done in mid to late summer when hypolimnetic phosphorus concentrations in Annabessacook Lake are greatest, and 95 percent of the hypolimnetic P was in the form of orthophosphate. Second, aluminum floc would chemically seal the sediment, preventing future phosphorus release. Through a hypolimnion application, maximum aluminum concentration could be achieved in the area of greatest release.

APPLICATION

The in-lake aluminum treatment of Annabessacook Lake was performed in August 1978. The technique used aluminum sulfate and sodium aluminate in combination to precipitate phosphorus in the hypolimnion. The use of the two chemicals was necessary to provide sufficient buffering capacity to mitigate potential pH shifts and aluminum toxicity in the low alkalinity water. A segregated dual injection system capable of delivering the chemicals simultaneously to any depth between 0 and 7 meters was designed. Aluminum application dosages in the top meter of treated water were 25 and 34 mg Al/l for areas 7 to 10 meters and over 10 meters deep, respectively.

The simultaneous placement of two chemicals over an area of 150 hectares at a depth of 7 meters presented a sizable logistical problem. Because of the large amounts of time and travel required to resupply, a single large capacity vessel rather than a number of smaller vessels was

Figure 2



chosen for the application. Both the commercial aluminum sulfate and sodium aluminate were obtained in liquid form for ease of handling. The chemicals were delivered to the lakeside base of operations at staggered intervals in 13.2 to 17.8 m^3 tank trucks. At the base, the chemicals were temporarily stored in two 1.2 x 5.49 meter diameter polyvinyl-lined swimming pools, erected especially for this project. The pools with a capacity of 28.8 m^3 each, proved to be very adequate holding facilities. The chemicals were pumped from the pools approximately 25 meters to a three-compartment, 23 m^3 mild-steel tank truck, mounted on a 12 m x 7.6 m barge (Figure 3). The barge, a series of iron pontoons, was transported from Portland, Maine and placed in Annabessacook Lake by the Maine National Guard.

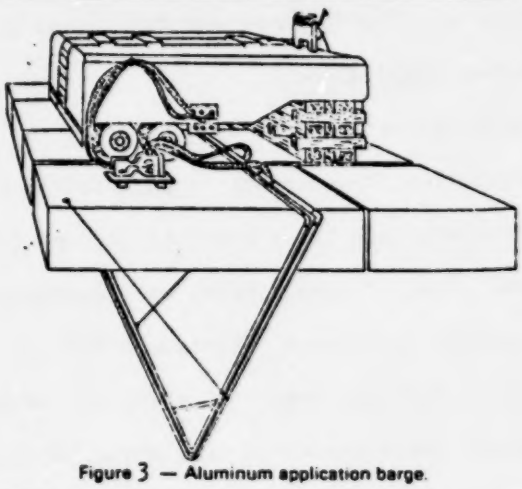


Figure 3 — Aluminum application barge.

The tank truck was valved so that each compartment could deliver its product via pumps to a completely segregated dual diffuser system. It was necessary to maintain complete separation of the chemicals, because contact led to the instantaneous formation of a precipitate which could clog the diffuser. The diffuser, constructed of 5 centimeter diameter black iron pipe

formed a 8.8 m x 7.6 m rectangle with 1.5 m extensions at each end of one of the longer sides. The other 8.8 m side rested in a cradle and straddled the barge approximately amidship, with the elongated side extending out over the bow of the barge. With this arrangement, the diffuser was able to pivot from a horizontal, above-water traveling position, to a vertical applying position, reaching a maximum of 7.5 meters below the water surface. The diffusing pipes were drilled with 6 mm holes every 15 cm over their 11.9 m lengths. The holes of the two pipes were positioned to coincide with one another and were angled to provide good chemical mixing when the system is in operation. The overall diffuser system weighed over 360 kilograms and was raised or lowered by a winch in the center of the barge, and a block-and-tackle on either side. The diffuser was positioned at 7 meters below the water surface during application.

The chemicals were delivered from the tank truck to the diffuser by two 3-horsepower gasoline driven pumps through sections of 5 cm diameter hose. Valving, both on the tank truck and in-line, and flow meters accurately regulated the chemical supply. Dosage rates were coordinated with barge speed and depth of area being treated. Surface trials of the system showed excellent floc formation and even dispersal along the length of the diffuser. The use of quick-connect hoses permitted easy and efficient flushing of the pumps and diffuser at the end of each day's application. Flushing was necessary because of the corrosive nature of the chemicals.

The barge was propelled by two powerboats (75 horsepower and greater), one on each side toward the stern of the barge. Steering was accomplished by varying the engines' speeds, and/or direction of thrust. This combination provided excellent maneuverability. The barge was able to maintain a speed

of 4.02 Km per hour under moderate wind conditions.

Aluminum treatment was carried out where depths exceeded 8 meters. The treatment route generally followed a pattern of decreasing concentric circles. To distinguish treated areas from untreated areas, buoys were dropped off the inside of the barge every 100 meters. On the next pass, a smaller circle inside the first, these buoys were kept to the outside of the barge, and the previously dropped buoys were picked up by trailing boats. This insured that the entire area would be covered, using a minimum number of buoys.

The aluminum application took approximately 18 days, averaging 10 hours per day for a standard crew of five persons. In addition, four to five local volunteers manning two to three boats were necessary to coordinate buoy placement and pickup.

There was a considerable amount of down-time during the application phase due to engine failures, tank leaks, and damage to diffusers. Despite these problems, approximately 95 percent of the area originally targeted for treatment received treatment.

8. WATER QUALITY RESULTS and DISCUSSION

METHODS

Lake Monitoring

Lake monitoring from 1977 through 1981 on Annabessacook Lake, Cobbossee Lake, and Pleasant Pond included secchi disk visibility, temperature and dissolved oxygen, total phosphorus, and chlorophyll-a; phytoplankton and winter zoobenthos sampling were also conducted on Annabessacook Lake. The monitoring period usually included the entire open water season (seven to eight months), and in 1978, 1979 and 1980 also included from one to three winter sampling events on each lake. Sampling frequency was highly variable and in some years increased greatly during summer. Annabessacook Lake received the most intensive monitoring for all parameters. The monitoring frequency differences between and within years are evident in Table 14. Cobbossee Lake monitoring usually ranged from monthly to biweekly, although south basin visibility monitoring frequency increased to weekly or greater during summers. Pleasant Pond monitoring ranged from less than monthly to biweekly and was the least variable and least intensive of the three lakes. The monitoring results reported in later sections as means for monthly, summer, or open water periods were time-weighted to account for changing sampling frequency. Table 14 summarizes sampling frequency for each lake.

Sampling stations on Annabessacook Lake were located at five sites in 1977 to determine the extent of both the zone of anoxia and phosphorus rich hypolimnetic waters. Monitoring was subsequently reduced to two sampling stations: #1 at the deep hole in the south basin (13m), and #2 in the shallow north end (7m) which was not part of the alum-treated area.

Table 14: Lake Monitoring Frequency

ANNABESSACOOK LAKE

	Jan	Feb	Mar[a]	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					----------open water----------							
1977												
Visibility					2	4	7	6	5	2	1	1
Oxygen/Temperature					2	3	6	6	5	1	0	1
Total phosphorus					2	2	2	5	5	1	1	1
Chlorophyll-a					2	2	2	2	2	1	1	1
Phytoplankton[b]					0	0	0	2	1	1	0	0
1978												
Visibility	1	0	0	0	1	3	5	4	4	3	2	1
Oxygen/Temperature	1	1	1	0	1	3	4	2	4	2	2	1
Total phosphorus	1	1	1	0	0	2	3	2	2	2	2	1
Chlorophyll-a	1	1	1	0	0	2	4	2	4	2	2	1
Phytoplankton	0	0	0	0	1	1	1	1	1	1	1	1
1979												
Visibility	1	1	1	2	3	3	12	14	7	3	1	0
Oxygen/Temperature	0	1	1	2	3	3	5	11	7	3	1	0
Total phosphorus	1	1	1	2	3	3	2	5	4	3	1	0
Chlorophyll-a	1	1	1	2	3	3	5	7	6	3	1	0
Phytoplankton	1	0	1	1	1	1	1	1	2	1	1	0
1980												
Visibility	0	1	1	2	2	3	8	7	4	1	1	0
Oxygen/Temperature	1	1	1	2	1	3	8	6	4	1	1	0
Total phosphorus	1	1	1	2	1	2	2	2	2	1	1	0
Chlorophyll-a	1	1	1	2	2	3	5	2	3	1	1	0
Phytoplankton	1	0	1	1	0	1	1	1	1	1	1	0
1981												
Visibility	0	0	1	1	1	4	5	5	5	2	1	0
Oxygen/Temperature			1	1	1	3	5	5	5	2	1	0
Total phosphorus	0	0	1	1	1	1	1	3	1	1	1	0
Chlorophyll-a	0	0	1	1	1	1	1	3	1	1	1	0
Phytoplankton	0	0	1	1	1	1	2	2	2	2	1	0

[a]Open water in 1981 due to early ice-out.

[b]Phytoplankton samples were saved and selectively analyzed based on other parameter results; the numbers given represent analyzed samples, except for 1981.

PLEASANT POND

	Jan	Feb	Mar[a]	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					----------open water----------							
1977												
Visibility					1	1	2	2	2	1	1	0
Oxygen/Temperature					0	0	1	2	2	1	1	0
Total phosphorus					1	1	1	2	2	1	1	0
Chlorophyll-a					0	0	0	1	0	1	1	0
1978												
Visibility	0	0	0	0	1	2	0	2	1	1	1	0
Oxygen/Temperature	1	0	1	0	0	2	0	2	1	1	1	0
Total phosphorus	1	1	1	0	0	2	0	2	1	1	1	0
Chlorophyll-a	1	1	1	0	0	2	0	2	1	1	1	0
1979												
Visibility	1	0	1	1	2	2	2	2	1	2	1	0
Oxygen/Temperature	0	0	1	1	2	2	2	2	1	2	1	0
Total phosphorus	1	0	1	1	2	2	2	2	1	2	1	0
Chlorophyll-a	1	0	1	1	2	2	2	2	1	2	1	0
1980												
Visibility	0	1	0	1	1	2	2	2	1	1	1	0
Oxygen/Temperature	0	1	0	1	1	2	2	2	1	1	1	0
Total phosphorus	0	1	0	1	1	2	2	2	1	1	1	0
Chlorophyll-a	0	1	0	1	1	2	2	2	1	1	1	0
1981												
Visibility	0	0	1	1	0*	3	2	1	1	1	0	0
Oxygen/Temperature	0	0	1	1	0	3	2	1	1	1	0	0
Total phosphorus	0	0	1	1	0	2	0	1	0	1	0	0
Chlorophyll-a	0	0	1	1	0	2	0	1	0	1	0	0

Table 14: (cont.)

COBBOSSEE LAKE, SOUTH

	Jan	Feb	Mar[a]	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					----------open water----------							
1977												
Visibility					1	1	2	2	2	1	1	0
Oxygen/Temperature					0	1	1	1	2	1	1	0
Total phosphorus					1	1	1	2	2	1	1	0
Chlorophyll-a					0	0	1	1	2	1	1	0
1978												
Visibility	0	0	0	0	2	0	0	1	2	1	1	0
Oxygen/Temperature	1	0	1	0	1	1	0	1	2	1	1	1
Total phosphorus	1	1	1	0	1	1	0	1	2	1	1	1
Chlorophyll-a	1	1	1	0	0	1	0	1	2	1	1	0
1979												
Visibility	0	1	0	1	1	3	2	4	2	3	1	0
Oxygen/Temperature	0	1	0	1	1	3	2	4	2	3	1	0
Total phosphorus	0	1	0	1	1	3	2	2	2	3	1	0
Chlorophyll-a	0	1	0	1	1	3	2	4	2	3	0	0
1980												
Visibility	0	1	0	1	1	2	5	8	5	1	1	0
Oxygen/Temperature	0	1	0	1	1	1	3	2	2	1	1	0
Total phosphorus	0	1	0	1	1	2	2	2	2	1	1	0
Chlorophyll-a	0	1	0	1	1	3	4	5	3	1	1	0
1981												
Visibility	0	0	1[a]	1	2	5	7	8	5	3	1	0
Oxygen/Temperature	0	0	1	1	1	2	3	3	3	2	1	0
Total phosphorus	0	0	1	1	1	1	1	1	1	1	1	0
Chlorophyll-a	0	0	1	1	1	1	1	1	2	1	1	0

COBBOSSEE LAKE, NORTH

	Jan	Feb	Mar[a]	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					----------open water----------							
1977												
Visibility					1	1	2	2	2	1	1	0
Oxygen/Temperature					0	1	1	1	2	1	0	0
Total phosphorus					1	1	1	2	2	1	1	0
Chlorophyll-a					0	0	1	1	1	1	0	0
1978												
Visibility	0	0	0	0	1	3	2	2	2	1	1	0
Oxygen/Temperature	1	0	1	0	1	1	0	1	2	1	1	1
Total phosphorus	1	1	1	0	1	1	1	1	2	1	1	1
Chlorophyll-a	1	1	1	0	0	3	2	1	2	1	1	0
1979												
Visibility	0	1	0	1	1	3	2	2	2	3	1	0
Oxygen/Temperature	0	1	0	1	1	3	2	2	2	3	1	0
Total phosphorus	0	1	0	1	1	3	2	2	2	3	1	0
Chlorophyll-a	0	1	0	1	1	3	2	2	2	3	0	0
1980												
Visibility	0	1	0	1	2	2	2	2	2	1	1	0
Oxygen/Temperature	0	1	0	1	1	1	2	2	2	1	1	0
Total phosphorus	0	1	0	1	1	2	2	2	2	2	1	0
Chlorophyll-a	0	1	0	1	2	2	2	2	2	1	1	0
1981												
Visibility	0	0	1	1	1	2	3	3	3	2	1	0
Oxygen/Temperature	0	0	1	1	1	2	3	2	3	2	1	0
Total phosphorus	0	0	1	1	1	1	1	1	1	1	1	0
Chlorophyll-a	0	0	1	1	1	1	1	1	2	1	1	0

Cobbossee Lake monitoring was conducted at the deep hole (30m) of the south basin, station 1, and the deep hole (20m) of the north basin, station 2. Pleasant Pond sampling was primarily at the deep hole (7m), station 1, with less frequent sampling conducted near the pond's confluence with Cobbossee Stream (station 2).

Visibility was measured with an 18cm secchi disk observed through a water scope. Water temperature and dissolved oxygen were measured with a YSI Model 51B meter, usually at depth intervals of one meter.

Phosphorus grab samples were collected with a Kemmerer sampling bottle at several depths per station to obtain a vertical profile of the water column. Annabessacook Lake phosphorus profiles extended to the lake bottom and included samples at every meter or every two meters. Cobbossee Lake and Pleasant Pond profiles were much less extensive; however, the number of samples and depth of sampling increased at both lakes following the implementation of lake restoration measures. Integrated core sampling replaced the grab profiles occasionally, particularly at overturn. All phosphorus samples were transfered in the field to glass Erlenmeyer flasks in 50 ml aliquots. All samples were analyzed for total phosphorus by the Maine Department of Environmental Protection (DEP) using digestion with ammonium persulfate, followed by ascorbic acid reduction and colorimetric analysis (a low level modification of EPA method 365.3 in EPA (1979)).

Chlorophyll samples were usually collected as integrated vertical core samples to a maximum depth of 10 meters, although grabbing samples from one or more depths was a method employed in the earlier periods of monitoring. Samples were stored on ice or refrigerated and within 24 hours were filtered through 47 mm Millipore filters having a .45 u pore size. (Occasionally samples could not be filtered within 24 hours and were instead frozen prior to filtration.)

The Maine DEP performed the chlorophyll-a analysis, following the 1973 EPA Biological Field and Laboratory Methods for pigment extraction by grinding in acetone, spectrophotometric measurement, and calculation of concentrations (Maine DEP, 1980).

Phytoplankton samples were 40 ml aliquots of the vertical core samples collected for chlorophyll analysis, and were fixed with formalin to a concentration of 5%. Analysis was performed by the Maine DEP on an inverted microscope using the Utermöhl method (Findenegg, 1971). Volume values were calculated by multiplying the number of cells per ml by an average volume for each species.

Zoobenthos samples were collected during late winter ice cover as five Ekman dredge samples near the deep hole. Samples were seived in the field through 533 u aperture, fixed with 5% formalin and stained with rose bengal. Maine DEP performed the taxonomic analysis. Organisms were sorted from the screen residue and preserved in a solution of 10:30:5:55 formalin, ethanol, glycerin and water. Chironomid larvae were mounted following the technique of Beck, 1976 and identified to genus or species as practical. Taxonomic classification followed that of Hamilton et al. 1969 (Courtemanch, 1982).

Lake surface elevations for Annabessacook Lake and Pleasant Pond were measured by U.S. Geological Survey wire weight gages. Cobbossee Lake elevations were measured and recorded hourly by a U.S.G.S. float-type stage recording gage with digital recorder. Lake depths were measured and mapped for Annabessacook Lake through a bathymetric survey conducted in 1977 by the Maine DEP and the Cobbossee Watershed District. Lake depths for Cobbossee Lake and Pleasant Pond were obtained from Maine Department of

Inland Fisheries and Wildlife maps (1977 Cobbossee Lake Survey, 1963 Pleasant Pond survey). Volume of depth intervals and whole lake volumes were determined by planimetry of depth contours from these maps and Hutchinson's formula (1975) for volume between horizontal planes of varying depths.

Stream Monitoring

Tributary monitoring was limited to total phosphorus and streamflow measurements. Phosphorus samples were 50 ml grab samples except for larger volume samples collected by automated sampler at Jock Stream. All phosphorus samples were analyzed by the Maine DEP as described in the lake monitoring section. Streamflow was measured at Jock Stream and Mill Stream by U.S. Geological Survey automatic stage recording gages, float-type and bubble gage respectively, with streamflow ratings and data processing performed by the U.S.G.S. Streamflow was measured at Jug Stream, the impounded outlet of Annabessacook and inlet to Cobbossee Lake, by wire weight gage determinations of water stage applied to a basic weir formula with discharge coefficients for broad crested weir flow provided by the U.S.G.S. All other streamflow was determined by applying water stage measurements to rating curves established by the U.S.G.S. for each stream.

Stream monitoring was conducted on the five major tributaries to Annabessacook Lake (Mill Stream, Hoyt Brook, Wilson Stream, Mud Mills Stream and Narrows Stream) from June through September 1977 and from April 1979 through September 1980. Monitoring was almost daily in 1977 and weekly in 1979-80 except for additional sampling during selected storm events. Phosphorus and streamflow data were used to determine phosphorus loading to Annabessacook Lake.

Jug Stream, the connecting tributary from Annabessacook to Cobbossee, was monitored from June 1977 through the present (1982), at approximately weekly intervals for phosphorus and weekly to daily intervals for streamflow. The data obtained were used in phosphorus budget determinations for Annabessacook and Cobbossee lakes and for assessing water quality changes in Annabessacook Lake.

Stream monitoring at Jock Stream, tributary to Cobbossee Lake, began in September 1977 and is ongoing. The Jock Stream monitoring was intended to assess water quality changes resulting from agricultural phosphorus runoff control, and was thus the most intensive stream monitoring project. Several discreet phosphorus samples were collected daily by an ISCO automated sampler, usually at six-hour intervals, during ice-free conditions (April through November). Samples were then chosen for analysis based on precipitation and runoff conditions. Winter samples were manual grabs ranging in frequency from weekly samples during non-runoff periods to multiple samples per day during storm events. Stream gaging measurements were recorded at 15 minute intervals through 1981 and at hourly intervals in 1982.

Stream monitoring at Potters Brook, a tributary to Pleasant Pond which drains agricultural lands, was conducted during spring runoff in 1979 and 1980. Monitoring frequency was several times a week to several times a day during storms or snowmelt.

Precipitation was measured at four stations in the Cobbossee Watershed, including one at the Jock Stream flow gaging station. Both rain and snow were collected in National Weather Service non-recording gages. The period of record for three of the gages is October 1977 through the present (1982); a gage located at East Winthrop has been operational since 1931.

ANNABESSACOOK LAKE

Phosphorus Loading

The restoration project was designed to achieve water quality goals in Annabessacook Lake by reducing agricultural phosphorus sources by 50-75% and by eliminating internal recycling from the bottom sediments. Restoration project monitoring included determination of external loading from May 1979 through September 1980 and internal loading for the summers of 1979 and 1980. In summary, while the total kilograms of incoming phosphorus were reduced, the reduction relative to the lower water budget indicates that external loading is still too high and does not necessarily reflect a response to agricultural controls; the internal loading, however, was greatly reduced following the alum treatment and showed an additional reduction in the second year of monitoring.

For the year September 1979 through August 1980, lower precipitation and runoff resulted in a flushing rate of 3.01 flushes per year (p) for Annabessacook, compared to 4.7 flushes monitored in 1975-76 and estimated for a year with normal runoff of 25 inches. Using the Larsen and Mercier formula (1976), the estimated phosphorus retention coefficient R for p=3.01 is .36. To attain the desired in-lake phosphorus concentration of between 12 and 15 ppb, the Dillon-Rigler model (1974), determines the appropriate external load as:

$$L_{crit} = \frac{15(5.3)(5.76)(3.01)}{1 - .36} = 2146 \text{ kg}$$

and

$$L_{perm} = \frac{12(5.3)(5.76)(3.01)}{1 - .36} = 1717 \text{ kg}.$$

The external load monitored was 2365 kg. While this is much lower than that monitored in 1975-76, (3460kg), it is excessive for the water quality desired, given the slower flushing rate. A reduction of 218 to 648 kg would achieve a lake concentration between 15 and 12 ppb, according to the model.

One major improvement evident from follow-up monitoring is the increase in the phosphorus retention capacity of the sediments, from -.32 in 1975-76 to .32 in 1979-80. Looking at the difference between influent and outflow phosphorus loads:

$$\frac{L_{ext}\ (2365) - P_{outflow}\ (1617)}{L_{ext}} = R = \frac{748}{2356}\ kg = .32$$

Not only has the retention coefficient changed from net release to net deposit, it also approaches the theoretical R of .36 for that year. The slightly lower measured R is probably due to the net release of phosphorus which still occurs during the summer, particularly during anoxic conditions.

Conversely, this R of .32 indicates that the internal loading has been greatly reduced. In fact, using the equation (Cooke, 1977):

$$\Delta P_{lake}\ (June\text{-}Aug) - (P L_{ext} - P_{out}) = P L_{int}$$

the internal loading for the summer of 1980 was only 350 kg. This is a reduction of 80% compared to the 1800 kg in 1976 and 1977. It appears then that the alum treatment was effective in sealing off a significant portion of the lake bottom sediments. In the first summer following the application (1979), internal loading from June to August was 535 kg, a 70% reduction, and 1980 showed even further improvements.

Table 15: ANNABESSACOOK LAKE PHOSPHORUS LOADING REDUCTIONS

	L_{ext} kg P	L_{int} kg P	R (p=3.01)	trophic state
post restoration monitored 1979-80	2365	350	.32	eutrophic
goal, modeled (P_1)=15; (P_1)=12	2146 to 1717	0	.36	mesotrophic
further reductions needed	-218 to-648 (9.2% to 27%)	-350		

If summer internal loading continued to decline until reaching zero, additional reductions of 9 to 27% in external loading would apparently achieve water quality goals in Annabessacook Lake.

Exact correlations between the relationship of phosphorus loading and concentrations in the Dillon-Rigler (1974) model and in Annabessacook Lake cannot be expected. Realistically, some release of phosphorus from the bottom sediments would be expected during the summer. While the severity of oxygen depletion should be lessened with diminishing algal blooms and phosphorus loading, a zone of anoxia will still remain during summer stratification. The model does not account for internal loading, thus the late summer lake concentration will be higher than the overturn concentration predicted from a given load.

Additionally, even without excessive seasonal internal loading, some variation will occur between predicted and measured values due to the differences between the lake's natural cycles and the model's assumptions. For example, the assumption that phosphorus is immediately mixed throughout the water column upon entering the lake is valid only during the spring and fall of the year. Also, the incoming phosphorus load is not constant over time, but instead fluctuates with runoff changes dictated by weather conditions. Nevertheless, the model remains useful for predicting phosphorus concentrations and indicating

reductions in loading needed to achieve a desirable water quality.

In-Lake Phosphorus

The phosphorus content of Annabessacook Lake shows a definite improvement since the 1978 alum treatment. Both maximums and means have been reduced, although the concentrations still remain high enough to support algal blooms. Mean open water phosphorus is now down to an average of 25.5 ppb, from 40.5in 1977, and mean summer is at 26.7 ppb compared to 44.3 ppb in 1977. Table 16 summarizes mean, maximum and minimum phosphorus values in Annabessacook for several years.

Table 16: ANNABESSACOOK LAKE PHOSPHORUS

	Period	Open Water Mean, ppb	Summer Mean, ppb	Maximum ppb, date	Minimum ppb, date
1977	5/5-11/3 d=183,N=18	40.5	44.3	76.0 9/12	17.1 5/5
1978*	5/1-11/27 d=211,N=14	31.0	34.8	49.5 7/31	22.8 6/23
1979	4/20-11/15 d=210,N=20	24.3	25.4	35.0 8/14	15.2 4/20
1980	4/14-11/4 d=205,N=12	26.3	26.6	35.4 9/3	20.1 6/19
1981	3/26-11/19 d=239,N=11	26.0	28.1	36.6 9/12	17.1 5/26

d = # days
N = # samples
*alum treatment in August 1978.

The reductions in internal loading discussed in the previous section have resulted in lower late summer phosphorus peaks. From spring or early summer, phosphorus concentrations rise until reaching a maximum, usually in late summer; the increase in kilograms has been calculated as:

		ΔP_{lake} kg	
pre	1977	+1736	
	1978	+1028	(to end of July, before alum)
post	1979	+ 585	
	1980	+ 429	
	1981	+ 538	

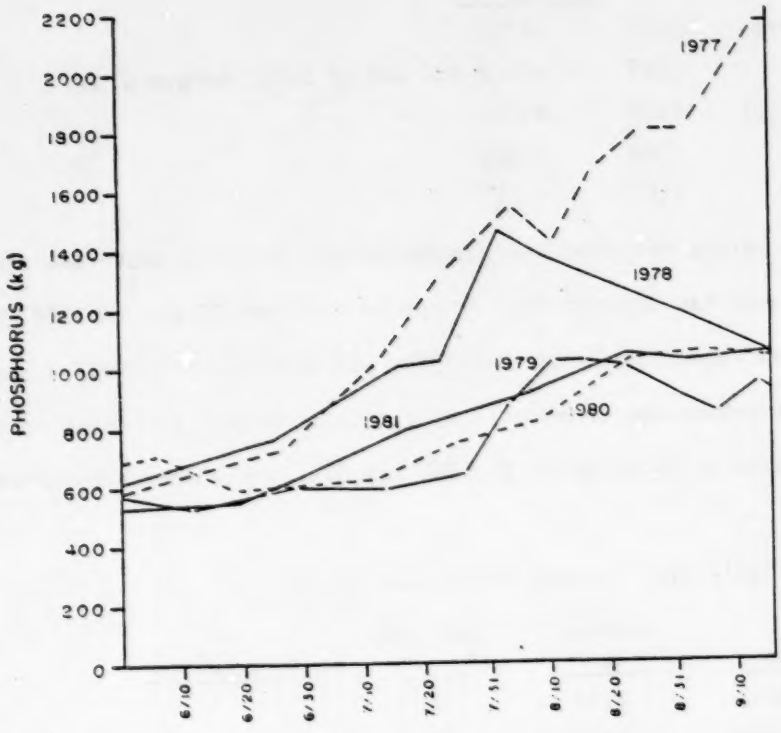
The maximum volume-weighted lake concentration for each year resulting from these increases has dropped from 76 ppb in 1977 and 50 ppb in 1978, to 35, 35, and 37 ppb respectively in 1979-1981. In comparison to 1977 alone (since the 1978 increase was interupted by the treatment), the three post-treatment years show a reduction of 54, 53, and 52% in maximum lake phosphorus concentration.

Table 17: Maximum Phosphorus In-Lake

	date	maximum kg P	vol.wtd P, ppb	% reduction
1977	9/12	2239	76	-
1978	7/31	1460	50	-
1979	8/14	1032	35	54
1980	9/03	1045	35	53
1981	9/21	1062	37	52

Figure 4 illustrates the differences in summer phosphorus content for 1977-1981; a table of kilograms and concentrations for each sampling date of each year can be found in Appendix C .

Figure 4: Summer P Increases - Annabessacook Lake



Hypolimnetic phosphorus concentrations still increase during the summer, indicating phosphorus release from the sediments during anoxia, but the alum treatment appears to have had a significant impact on this source. As with the whole lake, the hypolimnetic phosphorus concentration maximum was lower in 1979-81. From the beginning of summer to the maximum in late summer, the hypolimnetic weighted mean concentration increased as follows:

from 42 to 233 ppb in 1977,
from 20 to 105 ppb in 1979,
from 24 to 92 ppb in 1980,
from 20 to 83 ppb in 1981,

for a 55 to 64% reduction post-treatment.

An immediate effect of the alum treatment on hypolimnetic concentrations was apparent by the end of August 1978. Phosphorus measured at 12 m was 450 ppb

on 7/21 and 420 ppb 8/7; the alum was applied during August, and by 8/30, the 12 m concentration dropped to 190 ppb. In the following years, 1979-1981, the typical rise in hypolimnetic concentrations during summer occurred much more gradually, as shown in the graph of volume-weighted mean phosphorus in the hypolimnion (≥7m depth). Mean concentrations remained below 50 ppb until late July, compared to 150 ppb by that time in 1977 and 100 ppb in 1978. The measured concentrations in the bottom waters (12m) were 100 ppb until late July or early August, compared to 400-500 ppb in 1977 and 1978.

Figure 5

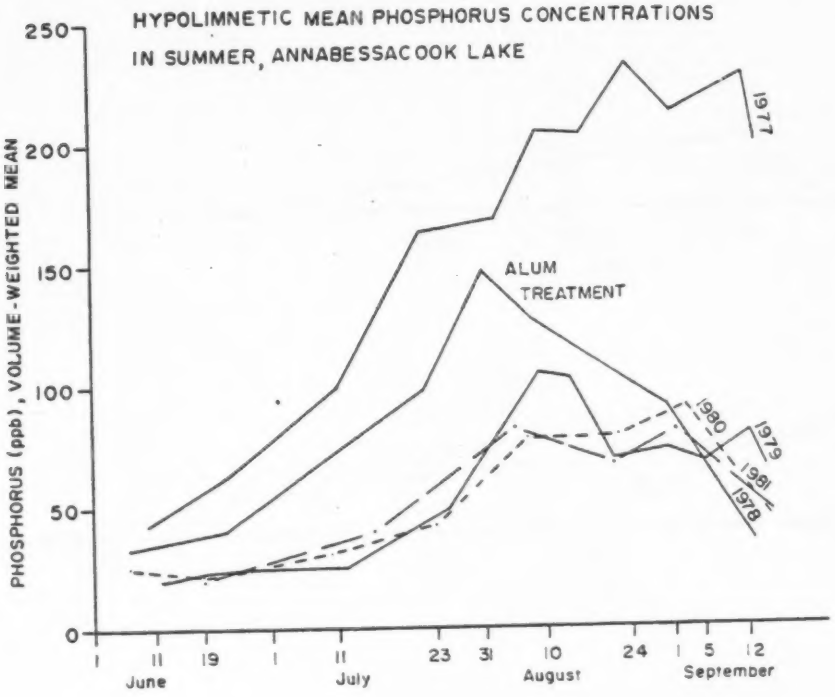
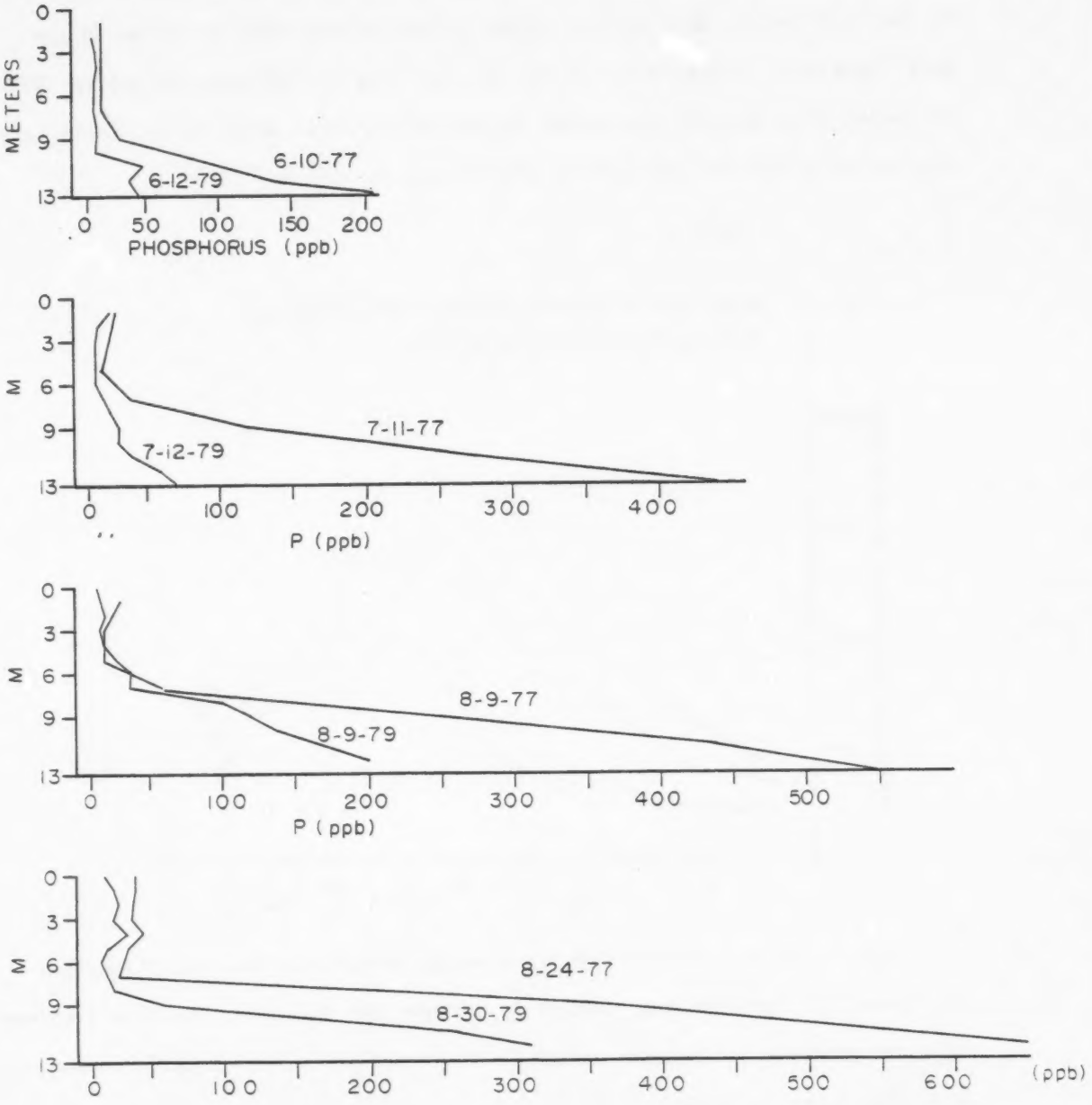


Figure 6 offers a comparison of selected phosphorus profiles throughout the summer for both the year preceding and the year following the alum treatment. While the greatest differences appear in the hypolimnion, epilimnetic concentrations were also lower in 1979.

Figure 6: Comparison of Summer Phosphorus Profiles 1977 and 1979, Annabessacook Lake



Response to Phosphorus Reductions

While the phosphorus data best reflect the direct impact of the restoration project, phytoplankton, chlorophyll, and visibility data also demonstrate progress toward the water quality goal of no algal blooms. An exact correlation between phosphorus and these other parameters was not expected, since meteorologic, morphologic, hydrologic, and other non-nutrient factors which are beyond the range of this study all impact lake productivity. The phytoplankton, chlorophyll, and visibility data all indicate water quality improvements. Table 18 shows some correlation among the summer means; particularly in the post-treatment years.

Table 18: Summer Mean Data for Annabessacook Lake

	Phosphorus ppb	Phytoplankton u^3/ml	Chlorophyll-a ug/l	Visibility meters
1977	44.3	8,671,555	18.3	1.5
1978	34.8	3,941,125*	21.1	1.9
1979	25.4	1,853,309	8.0	3.5
1980	26.6	4,400,106	10.2	3.4
1981	28.1	not available	12.7	3.2

*1978 phytoplankton is an underestimate since no samples were taken during the height of the bloom.

Additionally, benthic communities showed a positive response to the phosphorus reductions and the increased oxygen under ice cover that probably resulted from decreased algal blooms.

Phytoplankton:

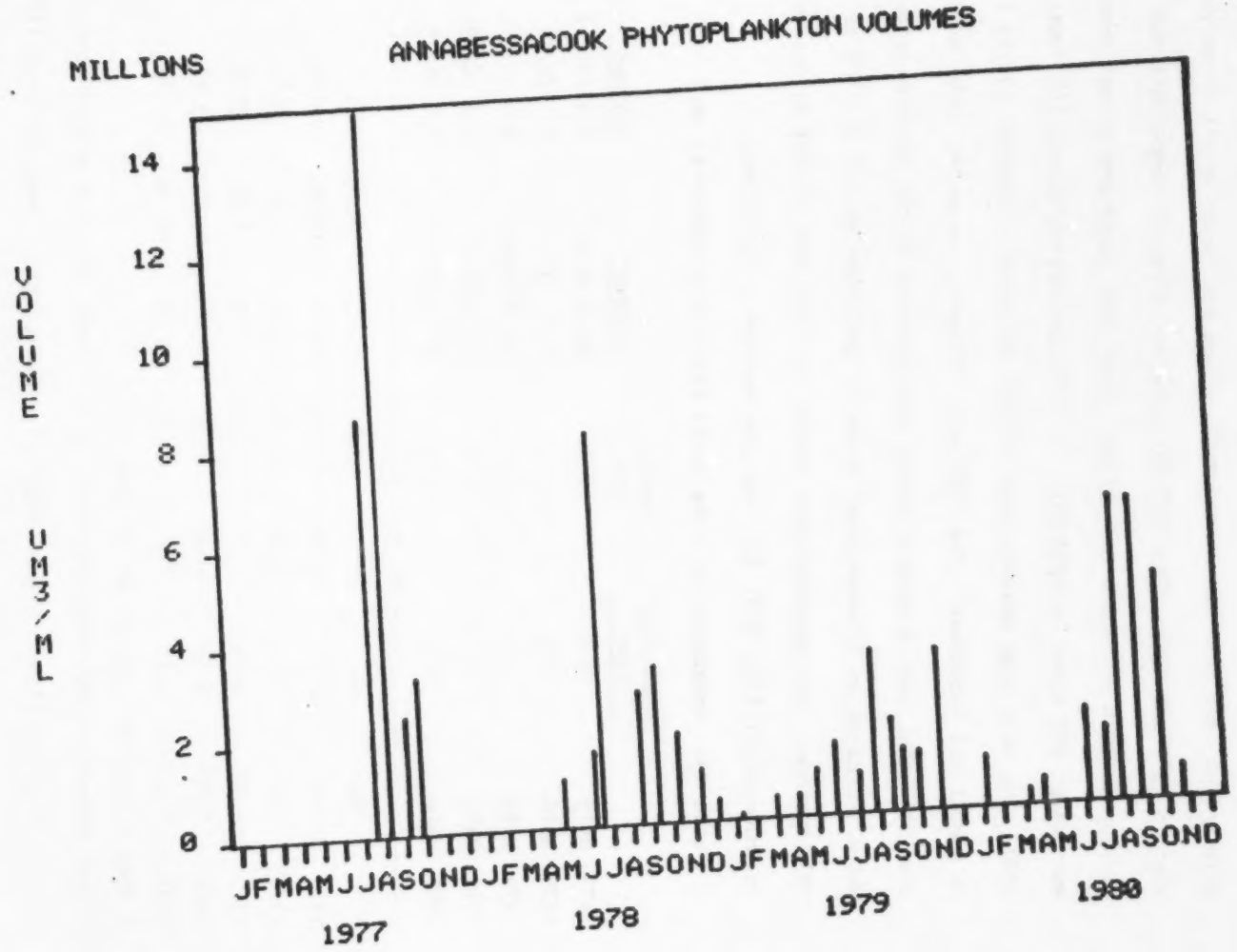
The annual phytoplankton succession of Annabessacook Lake is characterized by a moderately productive spring community dominated by Chrysophyta (diatoms and/or flagellates) or Euglenophyta (Trachelomonas) followed by a summer bloom

of Anabaena planktonica, Brunnthaler and Aphanizomenon flos-aquae (Lemmermann) Ralfs. These blue-greens are replaced by a generally less productive fall community dominated by Chlorophyta, Euglenophyta, diatoms or dinoflagellates (Ceratium Hirundinella). This pattern was essentially maintained throughout the period from 1977 through 1980.

Values for total phytoplankton volume (see figure 7) show this repeated annual pattern but also illustrate the major change during the period - the reduction in the intensity and duration of the summer blooms. The A. planktonica bloom in 1977 began in mid-July and peaked in late August with 14.9×10^6 u^3/ml. The highest value measured during the 1978 bloom (also A. planktonica) was 8.1×10^6 u^3/ml on July 3, but this underestimates the 1978 maximum because no sample was taken during the peak of the bloom, which occurred some three weeks later. During the aluminum treatment A. planktonica was replaced by a much reduced bloom of A. flos-aquae which continued through September. The 1979 bloom, which was comprised of both A. planktonica and A. flos-aquae, did not begin until early August and only reached a concentration of 3.3×10^6 u3/ml. The "bloom" was gone by the end of the month. In 1980 the bloom was denser than 1979 with 6.3×10^6 u^3/ml, but was still substantially less than in 1977 and 1978. The 1980 bloom was also of relatively short duration, beginning in late July and ending in mid to late August when A. planktonica was replaced by C. hirundinella. Samples from 1981 havenot yet been analyzed so the composition of that bloom is not known.

The dramatic reduction of phytoplankton biomass in 1979 parallels the similar reductions in chlorophyll and visibility.

Figure 7


ANNABESSACOOK PHYTOPLANKTON VOLUMES
MILLIONS
CU MM/ML VOLUME
14
12
10
8
6
4
2
0
JFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASOND
1977
1978
1979
1980

Chlorophyll-a:

Chlorophyll-a concentrations measured in 1979, 1980 and 1981 indicate a significant reduction in algal productivity in Annabessacook Lake. Table 19 illustrates that the mean chlorophyll values are lower in all three years than in 1977 and 1978. The 1977 data are not directly comparable due to varying methods of sample collection. Both open water and summer means were about 60% lower in 1979 than in 1978, and approximately 50% lower in 1980. The only high monthly mean in 1979 occurred in August, and in 1980, in August and September. The 1981 data, however, represent lower quality than the other post-treatment years, particularly in the maximum value, which indicates an intense algal bloom in September and is as high as the 1978 maximum. The seasonal mean values for 1981 show 27-40% reduction in chlorophyll from 1978, but indicate eutrophic conditions.

Table 19: Annabessacook Lake South Basin Chlorophyll-a, ug/l

		open water mean	summer mean	maximum[1]	minimum
1977	N=13	16.4	18.3	33.26(9/30)	7.42(5/26)
1978	N=16	18.2	21.1	41.6 (7/21)	6.1 (6/6)
1979	N=30	7.3	8.0	16.78(8/21)	3.06(5/31)
1980	N=19	9.3	10.2	24.03(9/3)	4.2 (6/19)
1981	N=11	13.3	12.7	42.8 (9/17)	2.9 (6/19)

Monthly Means

	Apr	May	June	July	Aug	Sept	Oct
1977	---	10.85	10.93	19.65	19.25	28.80	16.03
1978	---	---	7.66	29.49	24.65	17.21	17.78
1979	4.97*	4.80	4.31	6.51	12.98	8.24	7.18
1980	7.03*	5.36	4.40	6.99	14.44	15.52	9.52
1981	7.31	4.62	3.81	11.40	15.59	33.15	21.37

* Data for latter part of month only.

[1] Core samples. 1977 maximum during summer bloom was a 1m grab sample (58.28 ug/l).

Figure 8 illustrates chlorophyll concentrations measured from 1978-1981. The 1978 chlorophyll-a values soared in July, with concentrations of 28-42 ug/l

from mid-July to early August. This was accompanied by visibility of about 1 meter, with a minimum of 0.8 m recorded with the maximum chlorophyll. The sharp chlorophyll decline in late August coincides with the alum application, although these lowered concentrations at the end of the season still indicate high productivity; visibility only rose to around 2 m, and blue-green algae still dominated, showing a change in dominant species from Anabaena planktonica to Aphanizomenon flos-aquae. In comparison, 1979 shows moderate chlorophyll levels into mid-July; when concentrations did rise, the maximum recorded was 16.78 ug/l, compared to 41.6 ug/l the summer before. Consequently, secchi disk readings were from 2-3 m rather than at 1 m. Figure 9 shows the chlorophyll and visibility relationship in 1978 and 1979.

Chlorophyll values for 1980 were similar to 1979, except that high levels continued into September. In August 1979, dissolved oxygen and temperature data indicate that the weather conditions altered the lake stratification, which may have influenced the phytoplankton population shift from Cyanophyta (Anabaena planktonica) to Euglenophyta (Trachelomonas rotunda) and lowered chlorophyll values late in the summer. As shown in Figure 9, the visibility also responded and rose from 3.1 to 5.0 m on September 5th. In 1980, chlorophyll continued to rise in late summer and a higher maximum of 24.03 ug/l was observed (figure 8). This value is not directly comparable, as the core depth of sample was very shallow and only penetrated the area of densest algal residence. The value may also reflect the establishment of new species of algae. Young populations of algae have the highest chlorophyll concentrations (Bogorad, 1962), and phytoplankton data show that in late summer of 1980 the species dominance had changed from Anabaena planktonica to the phyrrophyte Ceratium hirundinella and the diatom Fragilaria crotonensis. Accordingly, the secchi disk visibility was better than during the period of blue-green dominance, due to the presence of C. hirundinella, which are less inhibitory to light penetration.

Figure 8

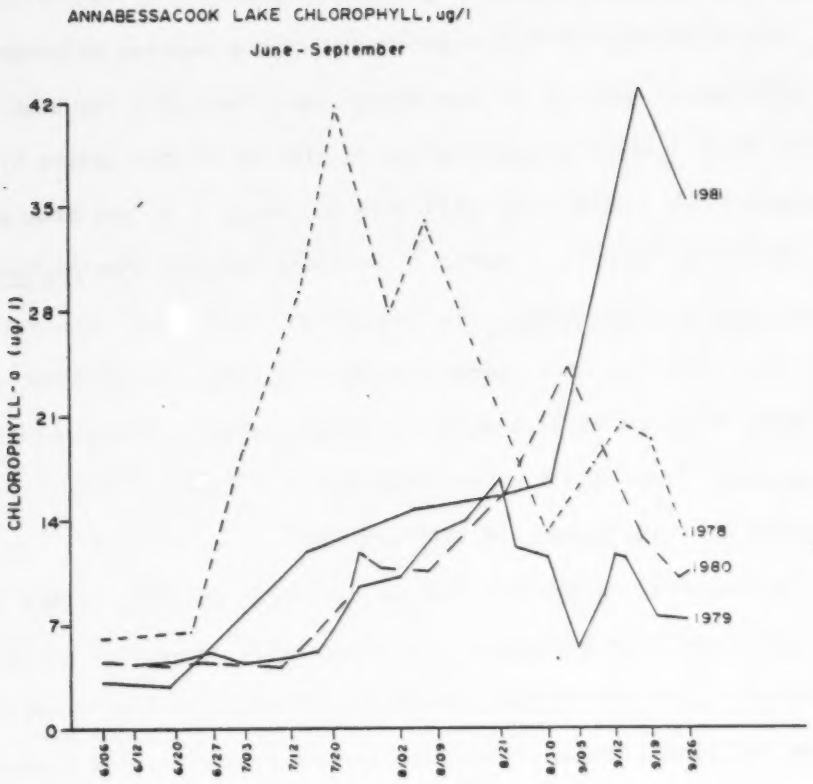
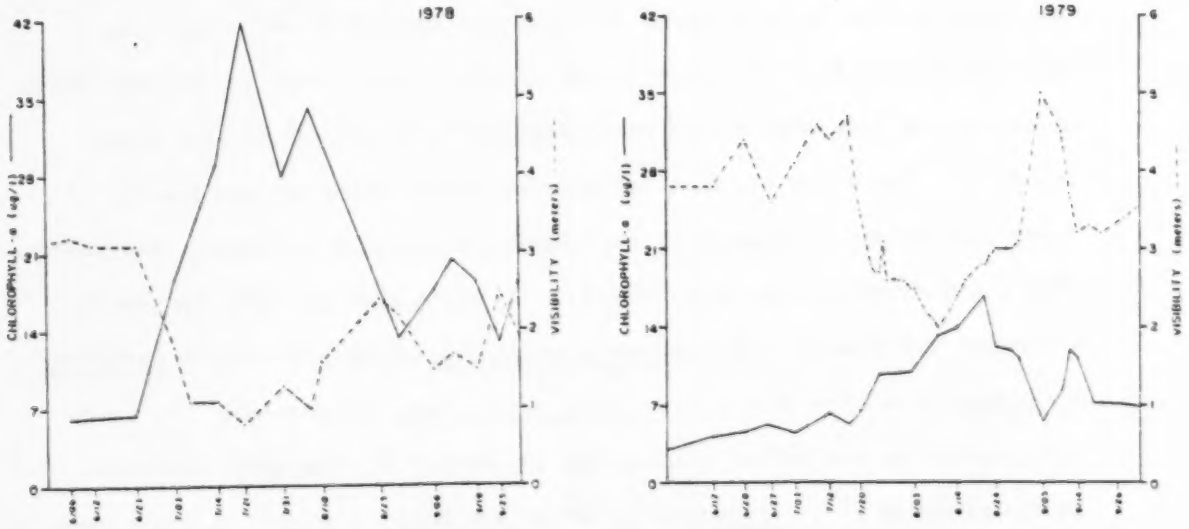


Figure 9: Chlorophyll-a and Visibility Comparisons



Thus, the maximum chlorophyll value alone does not reveal the shortened blue-green bloom or the improved visibility.

More differences appear in the 1981 data: the lowest June concentrations, elevated levels earlier in July, an extreme maximum in September, and continued high levels into October. The very low chlorophyll in early summer was accompanied by excellent visibility, 5 to 6 meters. This was followed by an algal proliferation earlier in July than in the other post-treatment years, perhaps because ice-out occurred very early in 1981, with stratification and warm epilimnetic temperatures developing earlier as well; however, the chlorophyll concentrations were still appreciably less then pre-treatment. The intensity of the bloom at fall overturn, with chlorophyll of 42 ug/l and visibility of 1.2 meters, is the major deviation in 1981 from the post-treatment water quality improvements measured by chlorophyll. The chlorophyll data for 1977-1981 is found in Table 2C, Appendix C .

Visibility:

Secchi disk visibility in Annabessacook Lake increased significantly in the year following the alum treatment (1979) to a better level of clarity than had been seen at any time in at least the previous decade. This improved visibility continued in 1980 and 1981, although the 1981 late summer visibility did not equal the improvements previously seen. Figure 10 compares June-September visibility from 1977-1981.

All three post-treatment years show higher mean visibility for both the open water season and the summer period, a shorter duration of depressed visibility (<3m) in summer, longer periods of good visibility (≥4m) in summer, and better visibility after fall overturn. The duration of severe bloom conditions (<2m) was significant only in 1981.

Figure 10: Annabessacook Lake Visibility
June - September

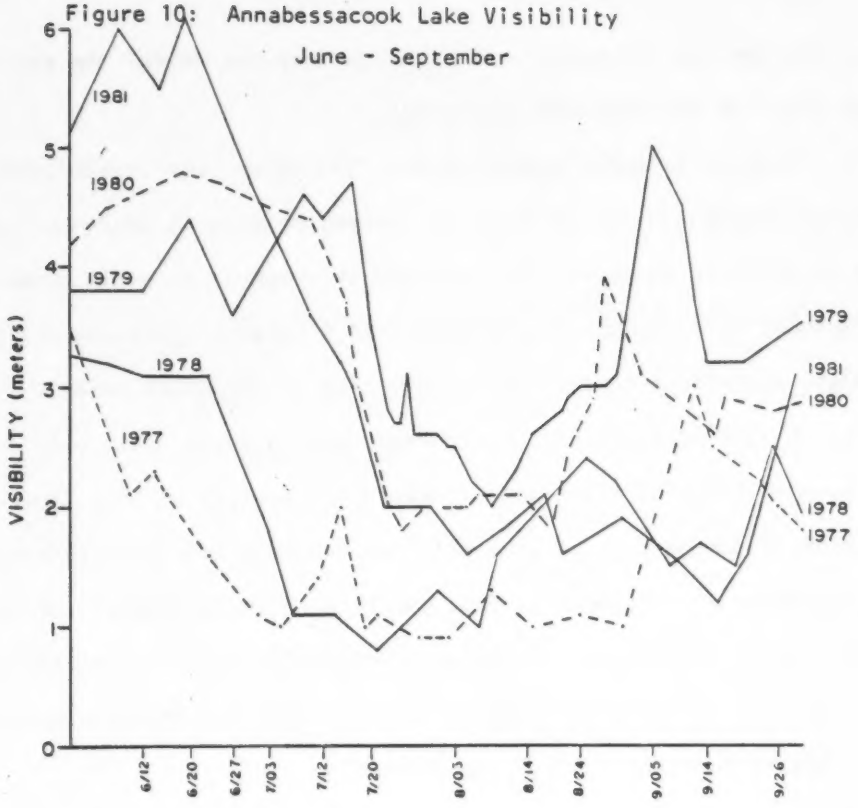


Table 20 and 21 summarize visibility for the period 1975-1981, and thus include data from before the project period. The alum treatment was conducted in August 1978; data from 1978 are included in the "pre-treatment" category since an intense algal bloom was evident by July, and because the alum was applied hypolimnetically. Secchi disk data exist prior to 1975 but were not observed with a scope to eliminate surface reflection; thus these data were not included in this comparison. Also, construction of the sewer line in 1972 is the major factor in differences in data from 1971 and 1972.

Mean visibility has increased by an average of nearly 1 m, from 2.0 - 2.9 m prior to the treatment to 3.3 - 3.6 m following the treatment. The increase in mean summer visibility is greater, averaging more than 1 m higher. This increased visibility is a more significant indication of water quality improvement, since summer is the period of the year when visibility is typically at its lowest and recreational use at its highest, and when internal loading occurs.

Table20: SECCHI DISK VISIBILITY (Meters): ANNABESSACOOK LAKE, SOUTH BASIN

Period	MEAN open water	MEAN summer	MAXIMUM open water	MAXIMUM summer	MINIMUM open water	MINIMUM summer	MEAN MONTHLY Apr	May	June	July	Aug	Sept	Oct
Pre-treatment:													
1975 4/29-9/22 (N=18,15)	2.9	2.8	4.8	4.8	1.4	1.4	-	3.6	4.0	2.7	2.1	2.0	-
1976 4/21-10/08 (N=12,7)	2.7	2.7	4.3	4.3	1.0	1.2	-	3.8	3.5	2.3	2.7	1.5	-
1977 5/05-11/16 (N=26,17)	2.0	1.5	3.5	3.0	0.9	0.9	-	3.2	2.0	1.2	1.1	2.2	2.1
1978 5/08-11/27 (N=22,14)	2.4	1.9	4.0	3.2	0.8	0.8	-	3.1	3.0	1.2	1.8	1.8*	2.7*
Post-treatment													
1979 4/18-11/15 (N=45,33)	3.6	3.5	5.0	5.0	2.0	2.0	-	3.4	3.9	3.8	2.6	3.8	4.0
1980 4/14-11/04 (N=28,19)	3.3	3.4	4.8	4.8	1.8	1.8	2.9	4.0	4.6	3.3	2.4	2.9	3.5
1981 3/19-11/19	3.4	3.2	6.1	6.1	1.2	1.3	3.8	4.4	5.6	3.0	1.8	1.8	3.1

* Also post-treatment
No means given for months with ≤½ month data.

Table 21: SECCHI DISK VISIBILITY DURATION - ANNABESSACOOK LAKE, SOUTH BASIN

	Open Water total days	days <2m (%)	days <3m (%)	days ≥4m (%)	Summer (June 1-Sept 14) total days	days <2m (%)	days <3m (%)	days ≥4m (%)
1975	147:	39 (26)	76 (52)	23 (16)	106:	39 (37)	65 (61)	18 (17)
1976	181:	29 (16)	108 (60)	11 (6)	106:	13 (12)	74 (70)	6 (6)
1977	196:	93 (47)	172 (88)	0 (0)	106:	79 (74)	105 (99)	0 (0)
1978	203:	75 (37)	117 (58)	1 (.4)	106:	60 (57)	83 (78)	0 (0)
1979	212:	0 (0)	31 (15)	56 (26)	106:	0 (0)	31 (29)	36 (34)
1980	205:	10 (5)	79 (38)	57 (28)	106:	10 (9)	48 (45)	43 (40)
1981	247:	52 (21)	88 (36)	75 (30)	106:	43 (40)	59 (56)	36 (34)

Pre-treatment summer means ranged from 1.5 - 2.8 m, while post-treatment summer means ranged from 3.2 - 3.5 m. The summer period is defined as June 1st through September 14th.

Maximum visibility observed in 1979-1981 has been excellent: 5.0, 4.8 and 6.1 m. The 1981 maximum of 6.1m was the highest recorded value for Annabessacook Lake.

Minimum visibility still reflects concentrated algal blooms, although in 1979 and 1980 the minimums were not as low as in pre-treatment years. The minimum visibility was 2.0 in 1979 and 1.8 m in 1980; in 1981, visibility declined to 1.2 m in mid-September.

Differences in duration of visibility levels (see Table 21) indicate other post-treatment improvements. Secchi disk readings of $<$ 2m represent severely impaired visibility, a common occurrence prior to the restoration project. Except for 1976 when visibility remained above this level until early September, the pre-treatment years experienced $<$2m visibility for 37%-74% of the summer period. The worst conditions occurred in 1977, when the visibility was $<$2m for 2½ months during the summer season as defined and over 3 months in all. The first two years of post-treatment monitoring demonstrated a break in this severely limited visibility. The summer of 1979 was totally free of $<$2m visibility, and in 1980 only 10 days exhibited visibility between 1.8 and 1.99 m. This improvement was not maintained in 1981, however, when 40% of the summer period experienced visibility $<$2m.

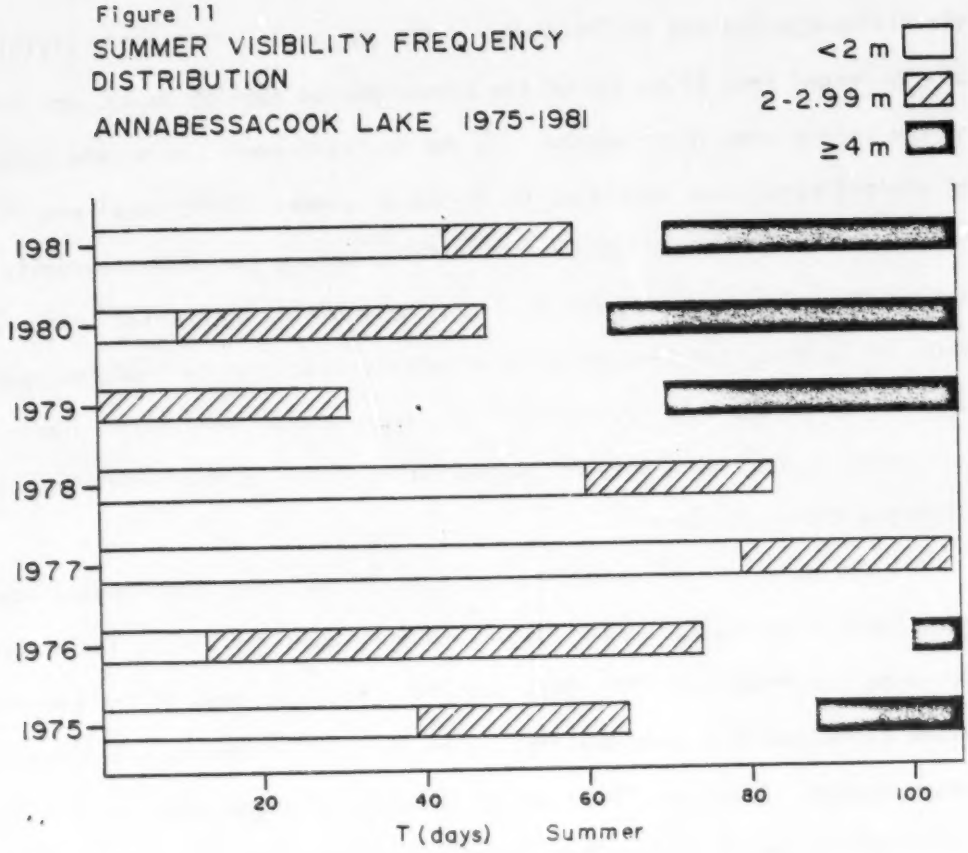
Table 21 also lists the number of days when visibility was $<$3m. While the $<$2m category is used to indicate severe algal blooms, visibility between 2 and 3 m corresponds to moderately high levels of algal production and greenish-colored lake water. Therefore, visibility $<$3m could be considered aesthetically undesirable. In the early 1970's, Annabessacook Lake had

visibility $<$3m for the entire summer. For the period 1975-1978, visibility of $<$3m ranged from 61 to 99% of the summer period (65-105 days), and 52-88% of the entire open water season. In the post-treatment years, the duration of visibility $<$3m was shortened to 29-56% of summer (31-59 days) and 15 to 36% of the entire open water season. Therefore, before the alum treatment, undesirable visibility ($<$3m) occurred for more than half of the open water season every year, while after the treatment, considerably less than half of the open water season experienced this low visibility. Improvements were particularly noticeable in 1979 when only one month out of seven in the monitoring period exhibited $<$3m visibility.

Not only is the visibility for most of the open water season now $\geq$3m, but a significant number of days of very good visibility (4m or greater) have also occurred. In 1979,1980, and 1981, 56 to 75 days of the open water season exhibited this good quality, with 36 to 43 of the days occurring during summer season. Also, in 1981 a period of visibility $\geq$5m occurred for the first time, lasting for 30 days. These extended periods of high clarity were not experienced prior to the alum treatment. In the early 1970's, visibility never reached 4m and seldom exceeded 3m. In 1977, visibility remained $<$4m for the entire year, and in 1978, only one day exhibited 4m in the main basin. The greatest duration $\geq$4m pre-treatment was 23 days in 1975.

A comparison of summer visibility is shown in Figure 11. Secchi disk observations for 1977-1981 appear in Table 3C, Appendix C .

Figure 11
SUMMER VISIBILITY FREQUENCY DISTRIBUTION
ANNABESSACOOK LAKE 1975-1981



Zoobenthos:

Prior to initiation of the restoration project, the benthic Chironomidae (Diptera) population was typical of other eutrophic lakes, with Chironomus plumosus type and Procladius as the dominant taxa. Samples collected in 1980 and 1981 following the aluminum treatment indicate a shift in community composition (Table 22). In 1980, Chironomus was still the dominant taxa, however, several new taxa were found. In 1981, three of these new taxa (Microtendipes, Paracladopelma, and Zalutschia) became the dominant taxa. Using Saether's, (1979), lake typology, it would appear that a shift had occurred from a eutrophic type community to a mesotrophic type in response to decreased primary productivity and improved hypolimnetic oxygen concentrations. The data indicate

that two or more years may be required for the benthic community to adjust to changing trophic state.

Table 22: Percent composition of Chironomidae in Annabessacook Lake

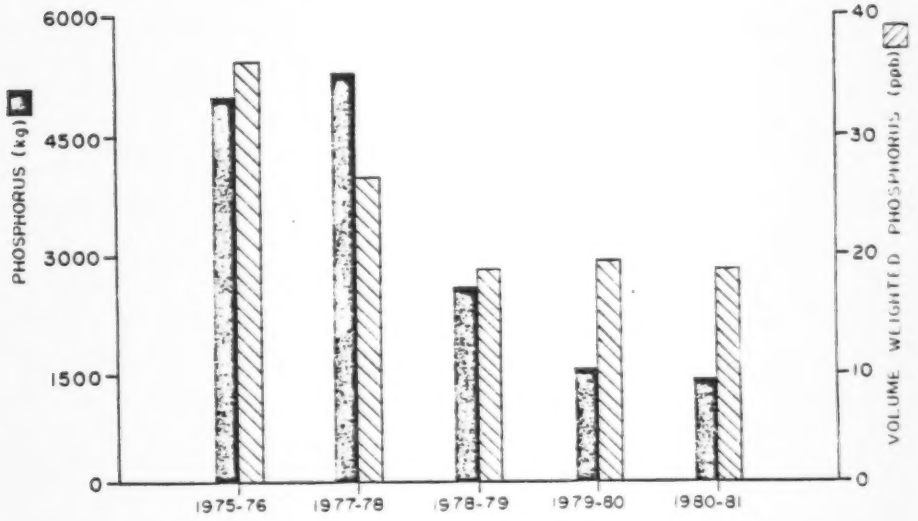
	1975	1976	1977	1978	1979	1980	1981
Procladius	50			20		2	9
Larsia						<1	
Chironomus	25	no	no	79	no	96	5
Dicrotendipes		sample	sample	1	sample		
Microtendipes		taken	taken		taken	<1	28
Paracladopelma						<1	12
Tanytarsus	25						9
Psectrocladuis							1
Zalutschia						1	35
Chironomid Lake Type	μ-eutrophic			μ-eutrophic		K-eutrophic	θ-mesotrophic

COBBOSSEE LAKE

Phosphorus Loading

. Phosphorus loading from Annabessacook Lake to Cobbosee Lake has been reduced since the alum treatment in 1978, and the level of improvement seen in the first year after treatment has been maintained through 1981. The two years of pre-treatment monitoring data showed the phosphorus load to be $\geq$ 5000 kg per year, or approximately one half of the annual load to Cobbossee. In the three post-treatment years, the annual load from Annabessacook was measured as approximately 1500-2500 kg, constituting about one third of Cobbossee's load. Figure 12 demonstrates changes in both total phosphorus load and volume-weighted concentration; the data were obtained from monitoring Jug Stream, the outlet of Annabessacook Lake.

Figure 12
ANNUAL PHOSPHORUS LOADING TO COBBOSSEE LAKE
FROM ANNABESSACOOK LAKE



The annual volume-weighted phosphorus concentration in Jug Stream was 19 ppb in each of the post-treatment years, compared to 36 and 26 ppb prior to the alum treatment. Thus, the water quality of Jug Stream is approaching the goal of $\leq$ 15 ppb; an additional phosphorus reduction of 20% would achieve this level.

Table 23: Phosphorus Loading to Cobbossee Lake via Jug Stream

	Kg P	m^3/s-days	cm runoff	vol.-wtd. P, ppb	L_{crit}[1] Kg P	reduction needed
Pre-treatment						
1975-76[2]	5000	1597.96	62.74	36.2	2072	58%
1977-78	5293	2318.05	91.01	26.4	3005	43%
Post-treatment						
1978-79	2544	1565.67	61.47	18.8	2030	20%
1979-80	1618	959.40	37.67	19.5	1244	23%
1980-81	1435	880.64	34.57	18.8	1142	20%

[1] L_{crit}= critical load for Jug Stream to deliver to Cobbossee Lake
[2] July 1975 - July 1976. All other annual periods are September 1 - August 31.

Agricultural runoff in the Jock Stream watershed remained a significant source of phosphorus loading to Cobbossee Lake throughout the monitoring period. In each year, the phosphorus measured in Jock Stream exceeded its theoretical critical load. The Jock Stream critical load was determined as follows: the total phosphorus critical load for Cobbossee Lake was estimated for each year using the Dillon-Rigler model with an in-lake phosphorus concentration of 15 ppb and the actual flushing rate calculated for each year from measured runoff; Jug Stream's critical load was computed for each year as 15 ppb P multiplied by measured streamflow; Cobbossee Lake's critical load minus the Jug Stream critical load yielded the critical load for the direct drainage; Jock Stream's allocation was based on the percentage of its contribution each year to the hydraulic budget of the direct

drainage area of Cobbossee Lake. The unusually low flushing rate of Cobbossee Lake in two of the years necessitated an exceedingly low phosphorus loading from Jock Stream in 1979-80 and 1980-81. Table 24 shows that, in three of four years, Jock Stream delivered more than twice its critical load to Cobbossee Lake.

Table 24: Jock Stream Annual Phosphorus Loading

	Kg P	cm runoff	vol.wtd. P, ppb	L_{crit} Kg P	reduction needed
1977-78[1]	1856	80.77	56	1485	20%
1978-79	2797	95.55	71	1300	52%
1979-80	1759	49.73	86	710	60%
1980-81	1400	39.37	87	679	51%

[1]September 1 - August 31 is the annual period for all years shown.

Construction of animal waste storage facilities on a majority of the farms in the Jock Stream watershed occurred during the period 1978-1981, and was not completed until late 1980 on several major farms. Therefore, only the most recent data, beginning with the September 1980-81 year, are valid for evaluating the results of the agricultural control program. As shown in Table 24, the total amount of phosphorus loading in 1980-81 was low (approximately 1400 kg), but the mean phosphorus concentration relative to the water volume was high (87 ppb) and the same as the previous year. (Detailed results and discussion of Jock Stream data have been reported separately (Dennis and Sage, 1981).)

Thus, Jug Stream and Jock Stream monitoring results indicate that both major phosphorus sources to Cobbossee Lake still need to be reduced, and in-lake monitoring (page 92) indicates that the desired lake water quality has not yet been achieved. According to the 1980-81 data, applied to the Dillon-Rigler model, a 22% reduction in phosphorus loading is needed to achieve

the critical 15 ppb concentration.[1] The modeling results also imply that the phosphorus retention coefficient, R, is approximately .35, which is much lower than the estimate of .59 obtained from the 1975-76 monitoring used to establish phosphorus loading goals and to predict the resultant in-lake phosphorus concentrations. This low retention coefficient may have been influenced by the low flushing rate (.73/yr) and unusual runoff conditions (minimal snowmelt and spring runoff) in 1980-81, and thus may not be representative. However, it may illustrate a state of increased stress from continually excessive phosphorus loading. If this degradation response has recently accelerated, then the lake's response time to recent and future loading reductions in Jug and Jock Streams may be greater than originally anticipated.

The first response to phosphorus loading reductions is expected in the south basin, which directly receives the two nutrient sources targeted for control. The north basin is somewhat cut off from the south by numerous islands, and it is possible that water circulating from the south basin to the outlet may bypass much of the north basin most of the time. This would delay water quality improvements in the north basin resulting from the reduced phosphorus levels of the south basin.

The consistently lower phosphorus loading observed in Jug Stream during the follow-up monitoring changes the relative significance of the two major sources to Cobbossee Lake. For example, in the period September 1980 - August 1981, Jug Stream and Jock Stream respectively contributed 36% and 35% of the phosphorus load to Cobbossee Lake; prior to the Annabessacook restoration project, Jug Stream and Jock Stream contributed 54% and 28% respectively. Preliminary results from 1982 Jock Stream monitoring, however,

[1]a. p= .73; L= 3951; P= 18.05 so R= .394. and P= 20.4 so R= .314.
b. avg. R= .35; P= 15; so L_{crit}= 3060.

indicate reduced winter and spring phosphorus loading. Therefore, both management priorities for phosphorus sources and needs for additional reductions are difficult to define at present and will be shaped by ongoing monitoring results.

In-Lake Quality

Phosphorus:

Open water season mean phosphorus concentrations used for trophic classification have been at or above the eutrophic level of 15 ppb in Cobbossee Lake for each of the last six years, although only by 3 ppb or less. This indicates that no reduction of in-lake mean phosphorus occurred during the restoration project, despite the reduced loading from Jug Stream, and also that the lake is only slightly over the threshold of a eutrophic condition. For example, Annabessacook Lake had a mean phosphorus concentration of 40 ppb before the restoration project and 26 ppb in each of the three post-treatment years of improved quality. In Cobbossee Lake, the open water mean phosphorus in 1976, 1977, and 1978 was 16 to 17 ppb (averaged between basins), and mean summer phosphorus was 15 to 17 ppb; in 1979, 1980 and 1981, which respresent the monitoring period following the Annabessacook alum treatment, the open water mean was 16 to 18 ppb and the summer mean was 15 to 17 ppb.

Table 25: Cobbossee Lake Phosphorus

	Mean Open Water	Mean Summer
1976	16.8	16.8
1977	16.4	14.6
1978	17.1	14.7
1979	16.5	14.8
1980	17.6	16.6
1981	18.0	15.8

The data for the pre-restoration project years are based on samples taken at depths no greater than 11 meters, thus excluding most of the hypolimnion in both basins. Beginning in 1979, phosphorus profiles included hypolimnetic samples to the lake bottom, and therefore only epilimnetic data are directly comparable to the previous years. All of the 1979-81 data are volume-weighted, however, and the whole lake values do not differ appreciably from the epilimnion values.

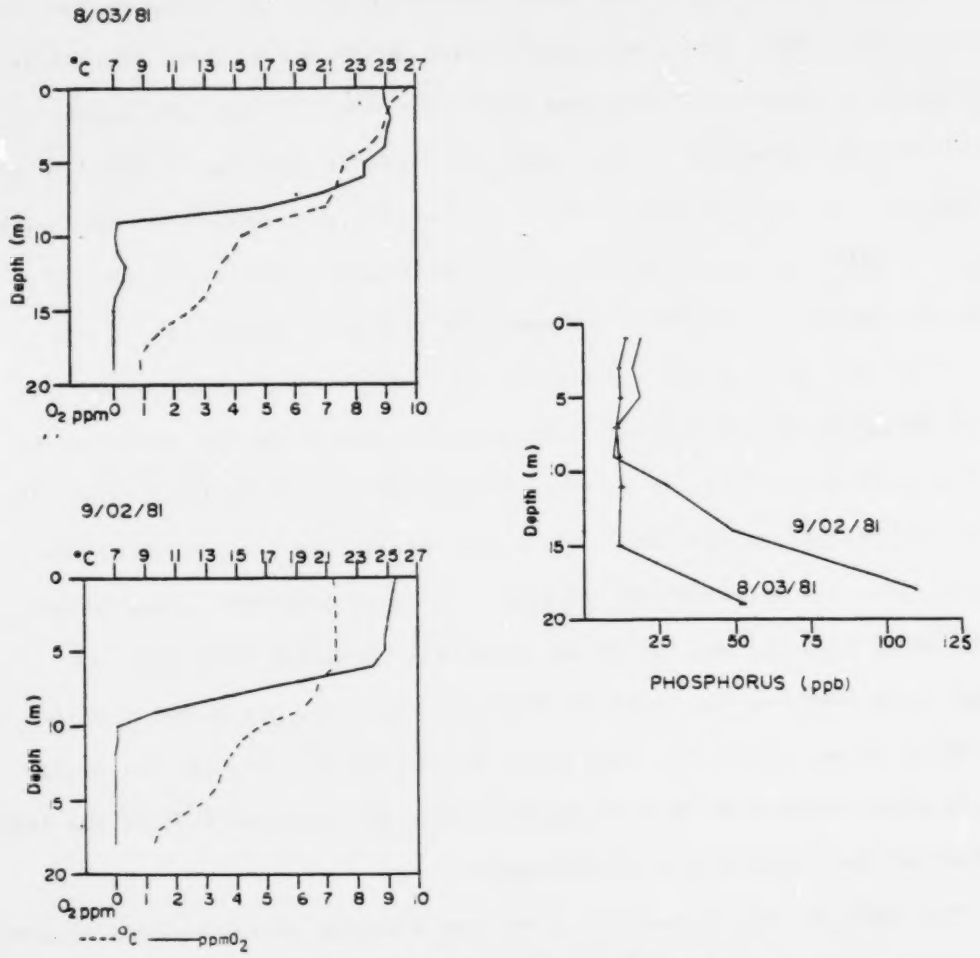
In each of the past three years, the north basin of Cobbossee Lake has experienced a short but severe algal bloom, evidenced by lower visibility and higher chlorophyll levels than previously seen. These late summer conditions were preceded by very good water clarity and low to moderate algal production for most of the summer. The hypolimnetic phosphorus data collection begun in 1979 provides information for investigating the possibility of internal phosphorus loading from anaerobic sediments during late summer.

From 1981 data, dissolved oxygen and temperature profiles show that, as of the beginning of August, severe anoxia (< 0.5 ppm O_2) conducive to sediment phosphorus release extended throughout the entire hypolimnion and into the thermocline (9m-19m). Since the anoxic zone extended into the thermocline, the potential for physical mixing of anaerobic, phosphorus-rich water into the epilimnion was enhanced. Profiles from later in August show that the top layer of anaerobic water did get mixed in before the major autumn overturn. This could be particularly significant since anoxic water covered an area of approximately 440 hectares (43% of the lake bottom) of the phosphorus rich sediments.

The 1981 phosphorus profiles show that elevated concentrations occurred only at the bottom of the hypolimnion in early August, with a volume-weighted hypolimnetic concentration of only 14 ppb. By early September, after one month of anoxic conditions, the entire hypolimnion showed an increase in

phosphorus concentrations; however, although the bottom water concentration was 110 ppb, near the top of the hypolimnion (11m) the concentration was only 28 ppb. In October, when fall overturn was almost complete in the north basin, concentrations appear nearly uniform and indicate the mixing of the hypolimnetic phosphorus into the upper waters. This may have been significant to the Aphanizomenon flos-aquae bloom which persisted during the fall.

Figure 13



TEMPERATURE, DISSOLVED OXYGEN AND PHOSPHORUS PROFILES

COBBOSSEE LAKE, NORTH BASIN 1981

Volume-weighted phosphorus values indicate that, during the first month of severe anoxia, the hypolimnetic phosphorus increased from 14 ppb to 34 ppb, the maximum measured for the year, and the epilimnion increased from 12.5 to 16 ppb; the phosphorus mass increase was 250 and 200 kg, respectively. The south basin phosphorus mass also increased, yet the main source of external loading (Annabessacook Lake) delivered only 100 kg during that time. Thus, there is a late summer phosphorus increase which is probably from internal recycling.

The south basin also showed an increase in both epilimnetic and hypolimnetic phosphorus after the development of severe anoxia from the thermocline to the lake bottom in August. The hypolimnetic increase was less than in the north basin, and the measured concentrations do not indicate a significant buildup of phosphorus-rich water over the bottom sediments in the deep basin. The epilimnion and whole basin phosphorus were often slightly higher than in the north and fluctuated up and down more during the summer. The south basin phosphorus data do not suggest an internal recycling problem from anaerobic sediment.

The significance of north basin internal phosphorus recycling is undetermined. The magnitude of the late summer increase is not great; additionally, a decline in visibility and increase in algal production occurs prior to noticeable phosphorus changes. The severity of the algal bloom (visibility = 1.1 m) was not anticipated, given that the epilimnetic phosphorus in the 1981 summer averaged $\leq$15 ppb and peaked at 16 ppb. The phosphorus measured during the spring, when much of the external loading occurs, yielded the highest whole basin and epilimnetic values of the year (24 and 25 ppb). Following this, phosphorus levels declined as sedimentation occurred during stratification, and the subsequent

Table 26

1981 NORTH Basin, COBBOSSEE LAKE

Total Phosphorus

	whole basin		0-9 meters		9m to bottom	
	Kg	ppb	Kg	ppb	Kg	ppb
3/24	1187	15.6	1031	16.4	156	12.0
4/28	1856	23.7	1584	24.6	272	19.7
5/26	1164	14.7	1003	15.5	160	11.1
6/18	1166	14.8	971	15.0	195	13.9
7/08	1086	13.7	888	13.7	198	13.9
8/03	1003	12.7	807	12.5	196	13.7
9/02	1448	18.8	997	15.7	451	33.8
10/01	1775	23.1	1389	21.9	386	28.9
11/09	1523	20.6	1288	20.9	235	18.9

1981 SOUTH Basin, COBBOSSEE LAKE

Total Phosphorus

	whole basin		0-9 meters		9m to bottom	
	Kg	ppb	Kg	ppb	Kg	ppb
3/24	1357	17.7	1124	18.8	233	13.8
4/28	1356	17.2	1010	16.5	346	19.7
5/26	1645	20.5	1360	21.9	285	15.8
6/18	1209	15.2	919	14.9	291	16.4
7/08	1298	16.3	1042	16.8	256	14.3
8/03	1096	13.7	825	13.3	272	15.1
9/02	1459	18.8	1047	17.3	412	24.0
10/01	1677	21.6	1225	20.3	451	26.3
11/09	1720	23.0	1389	23.8	331	20.3

ppb = volume weighted phosphorus

increase in phosphorus during the Anabaena bloom (19 and 16 ppb) did not reach spring levels. It appears that the external loading is still the most significant phosphorus source, probably providing most of the phosphorus which is recycled later in the summer. Continued algal blooms, however, can create thick algal mats on the lake bottom which provide a ready source of phosphorus for recycling in subsequent anoxic periods; thus, the potential exists for internal recycling in the north basin to become more significant if excessive phosphorus loading continues.

Chlorophyll-a:

Mean chlorophyll-a concentrations measured in Cobbossee Lake from 1979-1981 during open water ranged from 8.0 ug/l (south basin 1981) to 11.0 ug/l (north basin 1979), thereby classifying the lake as slightly eutrophic, according to the State of Maine standard of 8.0 ug/l.

Table 27: COBBOSSEE LAKE CHLOROPHYLL-A

		mean open water	mean summer
1979	S	8.28	7.61
	N	11.00	10.30
1980	S	9.26	10.11
	N	10.06	11.68
1981	S	8.02	7.31
	N	8.41	8.04

monthly means

		Apr	May	June	July	Aug	Sept	Oct
1979	S	10.62	4.49	4.73	3.58	10.80	15.28	10.39
	N	11.47	6.11	4.90	3.35	11.65	30.46	9.83
1980	S	6.55	4.91	6.18	4.81	14.88	18.47	8.48
	N	3.78	4.06	4.01	4.44	16.75	28.38	7.42
1981	S	5.84	4.42	2.63	4.34	10.13	18.01	10.98
	N	6.04	6.44	2.93	4.29	12.69	13.94	12.35

S = south basin, N = north basin

Except for an occasional high value at spring overturn, both lake basins exhibited low to moderate chlorophyll levels from ice-out through the end of July in each year. In August, however, concentrations increased and maximum levels indicative of high algal production were measured in late August or September in both basins in all years.

The most significant information gained from the chlorophyll data is found in the maximum values, particularly when compared to concurrent visibility and pre-restoration data (Table 28). The south basin chlorophyll levels indicated neither diminishing nor intensifying peak algal production from 1976 through 1981, with maximum values ranging from 16.1 ug/l (1978) to 22.5 ug/l (1981). Concurrent visibility values were 1.7 m (1981) to 2.3 m (1978); in three of the years, minimum visibility occurred several weeks after the maximum chlorophyll concentration, with the lowest south basin visibility recorded as 1.6 m in 1980. In the north basin, the 1979 and 1980 maxima of approximately 36 ug/l represent a noticeable increase from the range of 13.8 to 19.9 seen in the previous three years. The accompanying visibility observations also show more severe algal blooms. In recent years therefore, the north basin peak chlorophyll-a concentrations have been higher than in the south basin and reflect intensified algal bloom conditions.

Table 28: Maximum Chlorophyll-a and Corresponding Visibility

COBBOSSEE LAKE

	South basin				North basin			
	maximum chl-a ug/l	secchi disk,m	date	minimum visibility[1]	maximum chl-a ug/l	secchi disk,m	date	minimum visibility[1]
1976	18.79	1.8	9/17	s	14.48	1.6	9/17	s
1977	18.9	2.0	8/26	1.9 9/16	19.9	1.5	8/26	s
1978	16.1	2.3	9/05	2.0 9/26	13.8	2.1	9/05	s
1979	18.70	2.1	9/19	s	37.81	1.1	9/19	s
1980	21.27	2.2	8/21	1.6 9/04	34.58	1.1	9/04	s
1981	22.5	1.7	9/18	s	20.5	1.7	9/02	1.1 8/24[2]

[1] s = same (minimum visibility = visibility on day of maximum chlorophyll)

[2] In 1981, the minimum visibility was 1.1 m, but chlorophyll was not measured on that day; thus, chlorophyll levels in 1981 probably exceeded the maximum recorded concentration of 20.2 ug/l.

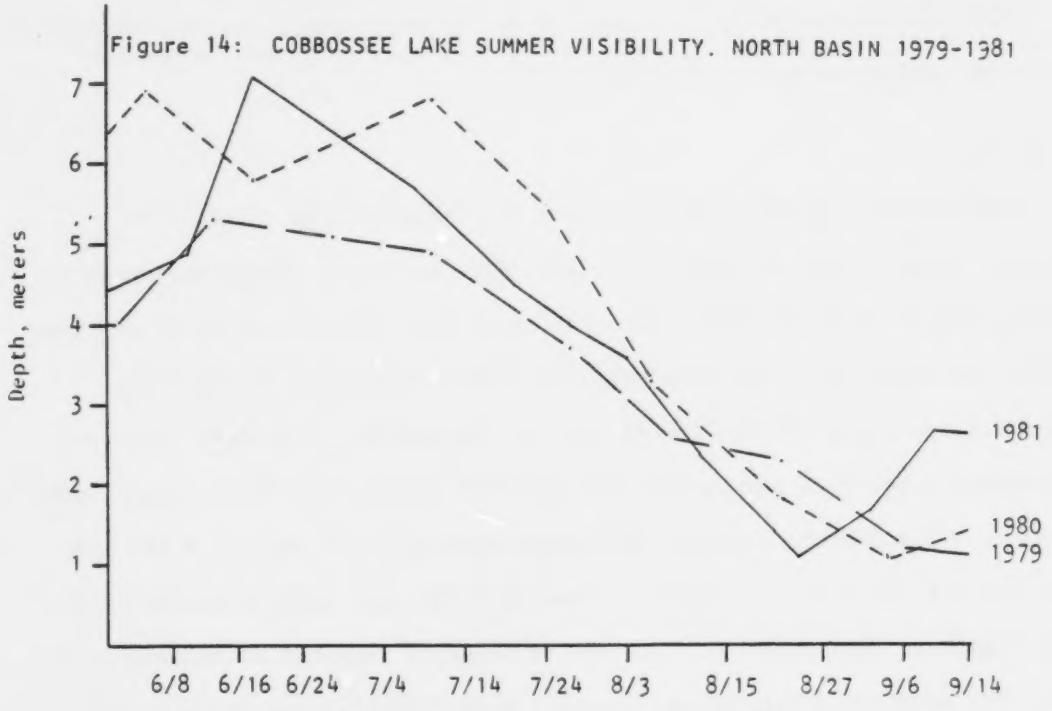
Visibility:

Pre-restoration visibility problems in Cobbossee Lake ranged from September algae blooms in 1975, 1976, and 1978, to 60-day blooms beginning in late July in 1973 and 1977. Both basins of the lake were affected by these blooms; the north basin exhibited slightly lower visibility during bloom conditions but higher visibility earlier in the season. Mean open water and mean summer visibility values for 1976 and 1978 ranged from 3.7 m (south, open water) to 4.6 m (north, summer); 1977 means were only 3.1 and 3.2 m for open water and 2.8 and 2.9 m for summer. Even with the poor quality exhibited in 1977, Cobbossee Lake visibility was not as severely impaired as Annabessacook Lake. The duration of blooms was shorter, mean visibility was higher, and some periods of each year experienced good visibility ($\geq$4m).

Restoration measures were implemented progressively throughout the period August 1978 through December 1981. During the three years following the Annabessacook Lake alum treatment, while agricultural controls were being

implemented on both lakes (1979-1981). visibility was very good from spring overturn through July, with all monthly means greater than 4 meters in both basins. Visibility fell rapidly in August and was < 3 m for much of August and usually all of September. The intensity of the algae blooms differed between basins; in the south basin, visibility was less than 2 m for 0-16 days/year, while the north basin maintained <2 m visibility for 20-33 days/year. Additionally, the blooms were more intense in the north basin where minimum visibility consistently dropped to 1.1 m, even lower than the pre-restoration minimum of 1.5-2.1 m. Figure 14 demonstrates the dramatic change in the north basin's water clarity which occurred during each summer from 1979-1981.

Figure 14: COBBOSSEE LAKE SUMMER VISIBILITY. NORTH BASIN 1979-1981



After overturn commenced, fall visibility was much higher ($\geq$4 m) in 1979 and 1980, and was fair in 1981 (>3 m) when an Aphanizomenon flos-aquae

bloom persisted. Mean visibility for open water and summer seasons was approximately 4 meters in both basins in all three years.

Thus, during the restoration project, Cobbossee Lake exhibited good water clarity as expressed by both the open water season and summer mean visibility; the lake also maintained good visibility from spring overturn until late summer; compared to pre-restoration data, a moderate improvement in south basin visibility appears. However, the late summer blooms persisted, and, in the north basin, appear to have intensified. Extended periods of poor visibility, such as in 1973 and 1977, were not experienced.

Secchi disk data for 1976-1981 are summarized in Tables 29 and 30, and in Figure 15, which illustrates the distribution of various visibility levels throughout the summer. Individual secchi disk observations can be found in Appendix D , Table 2D.

Table 29: SECCHI DISK VISIBILITY (Meters): COBBOSSEE LAKE

		MEAN Open Water	Summer	MAXIMUM[1] Open Water	MINIMUM Open Water	Summer	MEAN MONTHLY Apr	May	June	July	Aug	Sept	Oct
1976	S	3.8	3.9	6.5 6/24	1.8 9/17	2.1 9/03	3.8	5.5	5.8	3.5	3.4	2.1	2.8
	N	4.2	4.6	8.2 6/24	1.6 9/17	1.8 9/03	4.2	4.8	6.9	4.5	3.8	1.9	-
1977	S	3.1	2.8	4.2 6/28	1.9 9/16	2.0 7/20 8/5&26	-	3.8	4.0	2.7	2.0	2.4	3.6
	N	3.2	2.9	5.2 6/28	1.5 8/26	1.5 8/26	-	4.5	4.9	2.6	1.6	2.2	3.8
1978	S	3.7	☆	5.0 10/19	2.0 9/26	2.3 9/05	-	4.2	-	-	3.3	2 2	4 2
	N	3.9	3.8	5.2 7/5&13 10/19	2.1 9/05 9/26	2.1 9/05	-	4.6	4.3	4.6	3.2	2.2	4.3
1979	S	3.8	3.6	4.9 7/10	2.1 9/07 9/17	2.1 9/07	4.1	4.2	4.4	4.5	2.7	2.4	4.2
	N	3.7	3.6	5.3 6/13	1.1 9/19	1.2 9/07	4.4	4.4	5.0	4.4	2.4	1.6	4.0
1980	S	4.2	4.0	6.8 6/05	1.6 9/04	1.6 9/04	4.6	5.4	5.7	4.7	2.5	2.2	4.3
	N	4.4	4.4	6.9 6/05	1.1 9/04	1.1 9/04	4.9	5.5	6.3	6.0	2.5	1.7	4.1
1981	S	4.0	4.2	7.1 6/18	1.7 9/18	2.0 9/05	4.3	4.4	6.1	4.8	2 7	2.3	3.4
	N	3.9	4.0	7.1 6/18	1.1 8/24	1.1 8/24	4.4	4.1	5.8	4 9	2.2	2.4	3.4

S = south basin, N = north basin

[1]open water maximum = summer maximum except in 1978

☆insufficient data

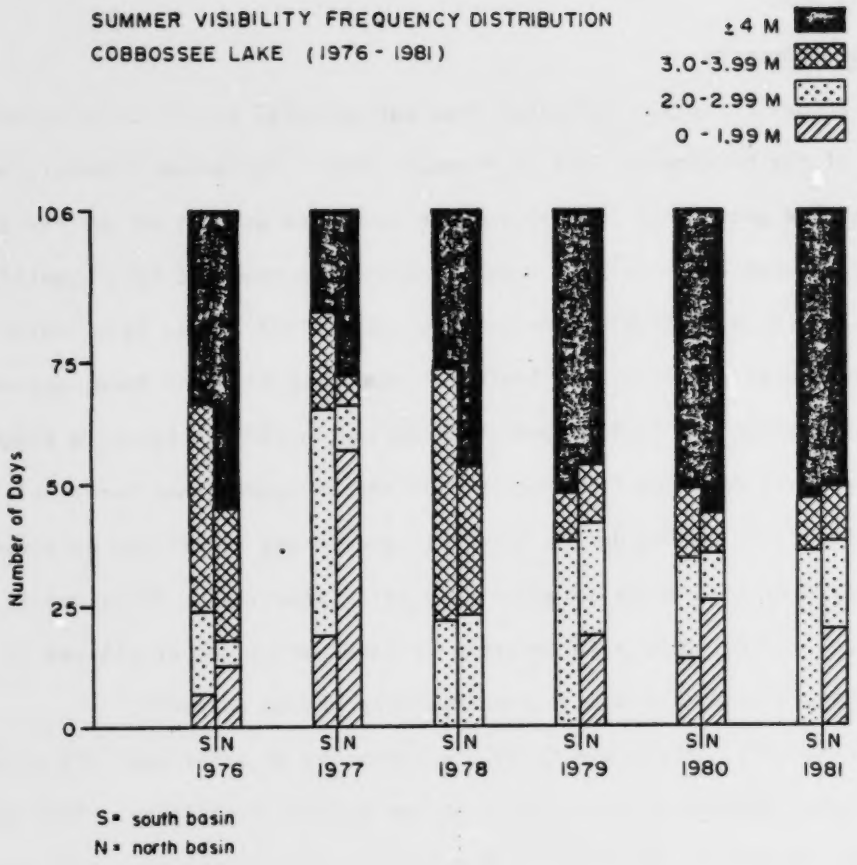
Table 30: COBBOSSEE LAKE VISIBILITY DURATION

Open Water Season

days of visibility at depth (meters):

		0-.99	1-1.99	2-2.99	3-3.99	4-4.99	5-5.99	6-6.99	7-7.99	8-8.99	total # days
1976	S	0	12	46	50	35	25	13	-	-	181
	N	0	22	13	43	43	14	14	13	2	164
1977	S	0	21	53	95	22	-	-	-	-	191
	N	0	60	17	60	42	12	-	-	-	191
1978	S	0	0	41	59	100	1	-	-	-	201
	N	0	0	41	49	93	18	-	-	-	201
1979	S	0	0	49	42	120	-	-	-	-	211
	N	0	28	28	28	103	24	-	-	-	211
1980	S	0	16	33	22	75	44	18	-	-	208
	N	0	33	19	21	49	40	46	-	-	208
1981	S	0	5	50	48	80	37	9	2	-	231
	N	0	20	39	53	71	23	18	2	-	231

Figure 15



Monitoring in 1982 will provide the first opportunity to assess the cumulative impact of the completed restoration measures. Monitoring for several more years will be necessary to better assess the lake's water quality trends. Annabessacook Lake and Jock Stream both enter Cobbossee Lake's south basin; therefore, visibility improvements should first appear there. Morphology and hypolimnetic anoxia present greater obstacles to recovery for the north basin, where more serious visibility problems have recently been observed. Thus, in the near future, reductions in phosphorus loading may have to compete with the stresses of past loading now evident in the north basin.

PLEASANT POND

Phosphorus Sources

Diagnostic studies estimated that agricultural runoff contributed 67-82% of the phosphorus load to Pleasant Pond. Follow-up tributary monitoring to determine phosphorus loading was not conducted as part of the restoration project; therefore, resultant loading reductions have not been quantified.

Agricultural controls were constructed in 1978 on six farms which previously had contributed 31% of the agricultural runoff to Pleasant Pond, according to land use estimates. Spring runoff monitoring in 1979 in Potter's Brook, which receives drainage from only two of the abovementioned farms, yielded high phosphorus loading during snowmelt, and manure runoff was observed from farms where winter manure spreading was still practiced. Additionally, phosphorus generated by a large storm in late spring was attributed to spreading winter manure accumulations on the snow-free ground in April.

During 1979, three more farms, representing an additional 31% of the agricultural phosphorus load, built manure storage facilities. Only one of these was located in the Potter's Brook drainage, and spring runoff monitoring in 1980 again showed high phosphorus levels in the stream. Part of this monitoring program focused on sample collection near a non-participating farm directly adjacent to Potter's Brook. Melting snow from manure-covered fields, channeled down a steep slope to the stream, yielded as much as 20,000 ppb total phosphorus. Several hundred feet downstream from this input, concentrations in Potter's Brook were 490 ppb. Phosphorus measured at this site during a rainstorm changed from 50 ppb when the farm runoff channel was frozen, to 300 ppb after the channel opened up. As much as 690 ppb phosphorus was measured at this site during spring runoff. Finally in 1981, a manure storage facility

was constructed at this farm; in total, farms generating an estimated 73% of the agricultural phosphorus loading to Pleasant Pond practiced improved animal waste management by the end of the project.

Elevated phosphorus levels in the Potter's Brook drainage were also measured in sedimented farm runoff during spring, 1980. Erosion controls have been implemented on some of the farms in the watershed of Pleasant Pond, but agricultural erosion may still be a phosphorus source to the pond.

In-Lake Quality

Phosphorus:

Phosphorus data from 1979-1981 do not clearly indicate lowered phosphorus levels in Pleasant Pond following the restoration project. Improvement is evident in comparison with 1976 values, but from 1977-1981, phosphorus values remained similar. In 1976, mean summer phosphorus was 26.9 ppb; values for all of the following years ranged from 18.4 to 21.2 ppb, with an average of 20.2 ppb. No phosphorus data exist for 1975 when the most severe algal bloom conditions were observed. Mean open water values show only slight differences, with 1976 values somewhat higher but not significantly so. The range for all six years was 19.4-23.7 ppb; both the lowest and highest values are from pre-restoration period data.

Table 31: PLEASANT POND PHOSPHORUS, ppb

	period	# dates sampled	mean open water	mean summer	minimum[1]		maximum[1]	
1976	4/20-10/19	11	23.7	26.9	15	5/18	35	8/6 & 25
1977	5/12-11/21	9	21.0	20.9	16	6/29	29.5	7/26
1978	6/01-11/16	7	19.4	19.4	16	6/01	21.9	8/15
1979	4/20-11/09	13	21.9	18.4	15.7	7/26	42.1	11/09
1980	5/15-11/07	10	22.3	20.9	16.1	7/10	30.9	8/22
1981	3/26-10/06	6	21.0	21.2	17.7	4/28	24.8	3/26

[1]minimum and maximum values are volume-weighted daily values.

The frequency and type of phosphorus monitoring varied from year to year, thus presenting problems with data comparison. The lowest open water mean value (19.4 ppb) obtained from 1978 data does not include any samples before June 1st, and thus probably underestimates the open season phosphorus, since values are usually high at some time during spring. Phosphorus profiles included samples from no more than three depths, due to the pond's shallowness (maximum depth = 7.9m). Since almost 80% of the lake volume is $\leq$ 3m, samples collected from 0-3m largely determine the overall phosphorus content. Grab samples in 1977 and 1978 were generally not collected above 3m, and thus the in-lake phosphorus may be underestimated in those years; phosphorus values are likely to be higher at 1 or 2 m during certain periods due to algal accumulation, and in 1980 and 1981, 1m values were noticeably higher on several occasions. The 1976 data are from cores, and therefore integrate the whole water column but are not volume-weighted. Core values or volume-weighted values from individual grab samples are listed for each year in Table 32.

Table 32: Pleasant Pond Open Water Season Phosphorus, ppb

1976		1977		1978		1979		1980		1981	
4/20	22	5/12	20	6/01	16	4/20	18	5/15	27.7	3/26	24.8
5/18	15	6/29	16	6/29	18.8	5/09	27.2	6/05	17.3	4/28	17.7
6/13	19	7/26	29.5	8/15	21.9	5/30	26.8	6/19	18.5	6/02	19.8
6/28	20	8/18	17	8/31	19.1	6/12	15.9	7/10	16.1	6/29	21.6
7/11	24	8/29	20	9/28	20.6	6/28	19.3	7/24	22.3	8/21	20.9
8/06	35	9/19	27	10/17	20	7/10	18.5	8/06	20.4	10/06	23.9
8/25	35	9/27	22	11/16	16.7	7/26	15.7	8/22	30.9		
9/06	30	10/12	18.8			8/07	18.4	9/04	20.7		
9/16	23	11/21	23.2			8/31	17.3	10/07	27.1		
10/05	21					9/17	24.4	11/07	22.2		
10/19	19					10/01	21.9				
						10/19	22.5				
						11/09	42.1				

Pleasant Pond does not typically experience a late summer phosphorus increase which could trigger algal blooms. High or maximum phosphorus values

were often measured during well-mixed conditions in spring or fall. In both 1976 and 1980, however, phosphorus increased almost 10 ppb in August to 35 and 31 ppb, respectively. Correspondingly, chlorophyll-a levels increased and visibility decreased. These intermittent late summer phosphorus increases may be caused by internal recycling, but not by means of anoxic sediment release. Sampling of the bottom waters from 1979 on shows that the highest bottom phosphorus measured during anoxia was only 27 ppb, and the maximum bottom phosphorus recorded was 34 ppb. The anoxic zone comprises no more than 7 percent of the lake's volume and would not be a significant source even if it produced high phosphorus concentrations.

Phosphorus values at 1m were 9 to 18 ppb higher than at the next depth measured (usually 3m) on four of eleven sampling dates in 1980; bottom samples on these dates were very similar to the 3m values. The occurrences ranged from spring through fall, and corresponding visibility ranged from 2.4 to 5.4m. In 1981, higher values were also observed at 1m, particularly in June when both 9 ppb and 10 ppb differences were measured. Secchi disk visibility was 4.6 and 4.1m. The phosphorus values were $\geq$24 ppb and reached 42 ppb in August 1980. These high surface values, often accompanied by good visibility, may be a function of the pond's color; the reduced light penetration would be more conducive to algal clustering near the surface, yet much of the phosphorus may be tied up in organic acids and unavailable for photosynthesis.

The color (40 ptu) also prohibits trophic classification from mean phosphorus values, since the phosphorus levels will usually predict higher productivity than actually measured in colored water. The mean open water phosphorus of 21 and 22 ppb in 1979, 1980, and 1981, however, are still above a desireable level for Pleasant Pond.

Chlorophyll-a:

Chlorophyll-a concentrations in Pleasant Pond reveal moderately high productivity, although extreme values associated with intense algal blooms are not consistently observed from year to year. From the most recent data (1981), the pond does not appear to be highly eutrophic. The open water season mean of 6.26 ug/l is lower than in Annabessacook Lake and Cobbossee Lake, and yields a Maine State trophic state index (TSI) number of 59 (on a scale of 0-100, low to high productivity). More importantly, the maximum value was 9.9 ug/l, accompanied by visibility of 2.6 m.

While the 1981 results approach acceptable standards, similar conditions appeared in the 1978 data, and the fluctuation between years from 1976 through 1981 precludes definition of a water quality trend (see Table 33).

Table 33: PLEASANT POND CHLOROPHYLL-a, ug/l

	period	# samples	Open water mean	summer mean	Maximum monthly mean	maximum	visibility (m) on date of chl. maximum
1976	4/20-10/19	13	6.01	6.78	11.66 Sep	17.14 (9/06)	1.4
1978	6/01-11/16	7	5.62	5.37*	9.38 Sep	9.5 (9/28)	2.4
1979	4/20-11/09	13	5.95	5.23	9.36 Sep	13.41 (10/01)	2.5
1980	4/22-11/07	11	9.09	7.41	17.41 Sep	20.02 (10/07)	2.0
1981	3/26-10/06	6	6.26	7.07*	9.24 Aug	9.0 (8/21)	2.6

*No July data

Maximum chlorophyll-a concentrations corresponded to minimum or within .2 m of minimum visibility in each of the five years monitored.

However, not all periods of undesireable visibility are accompanied by high productivity. Only slightly more than half of the chlorophyll concentrations measured when visibility dropped below 3 m were high, and occasionally were very low; for example, on April 22, 1980, the chlorophyll-a measured only 2.53 ug/l but visibility was down to 1.8 m. Additionally, while all of the maximum values were observed in late summer or early fall, some high concentrations were measured for brief periods in spring or early summer in some years. Thus, significant productivity defined by mean chlorophyll-a is influenced by high concentrations not exclusively associated with late summer Anabaena blooms. However, the intermittent blue-green algal blooms will remain a focus for improvement.

Visibility:

Visibility monitoring in 1975 and 1976 during the diagnostic study of Pleasant Pond revealed periods of intense algal bloom conditions, with < 2 meter visibility occurring in August and September. The visibility problems were most severe in 1975, when visibility dropped to 0.9 meters in late August. Most of the sampling period in 1975 (6/27-9/17) exhibited undesireable visibility (<3 m); mean summer visibility was only 2.4 meters, and visibility only reached 4 meters on one observation date.

Better visibility was observed in Pleasant Pond in 1977 and 1978, while manure storage facilities were being planned or constructed but were not actually in use. Visibility remained above 2 meters at all times and the minimum of 2.4 m in both years was 1.0 to 1.5 meters higher than in 1975 and 1976. A period of low visibility may have occurred during a monitoring gap in July 1978, but this is unlikely since July is often the period of best visibility in Pleasant Pond and preceding and subsequent observations were ≥ 4 m. The 1978 mean visibility values are weakened,

however, by this lack of data. It appears that in both years summer visibility was higher and did not fall below 3 m until September.

From 1979 on, when animal waste runoff controls were being implemented, the visibility remained better than the 1975 and 1976 values, but was very similar to 1977 and 1978. Mean open water visibility ranged from 3.2 to 3.7 m, the same as the 1977 and 1978 range. Summer means ranged from 3.6 to 4.0 m, compared to 3.6 and 3.8. Visibility only fell below 2 meters at spring overturn in 1980 (minimum = 1.8 m), and only one month or less in summer exhibited visibility <3 m. Visibility measured near the confluence with Cobbossee Stream was similar to, but slightly higher than the main section of the pond in each year, probably due to the stream's high water quality.

A new maximum visibility value was obtained in 1980. The August 6th observation of 5.6 m is one meter higher than any previous value, and thus the three weeks of visibility ≥ 5 m in the summer of 1980 was the best recorded for any period in all years. Table 34 summarizes visibility from 1975 through 1981. Individual visibility measurements for 1977-1981 appear in Appendix E.

Table 34: PLEASANT POND VISIBILITY (meters). Station 1

	Monitoring Period	Mean Open Water	Mean Summer	Maximum	Minimum
1975	6/27- 9/17	*	2.4	4.0, 7/22	0.9, 8/25
1976	4/20-10/19	3.2	3.2	4.4, 6/28	1.4, 9/06
1977	5/12-11/21	3.2	3.6	4.5, 7/26	2.4, 5/12, 9/27
1978*	5/08-11/16	3.7	3.8	4.4, 10/17	2.4, 9/28
1979	4/20-11/09	3.2	3.6	4.5, 8/07	2.4, 11/09
1980	4/22-11/07	3.4	4.0	5.6, 8/06	1.8, 4/22
1981	3/26-10/06	3.7	3.6	4.6, 6/29	2.6, 8/21

	total days	# days Open w.	2m Summer	# days Open w.	3m Summer	# days 4m	# days 5m
1975	83	31	31	62	59	1	0
1976	183	19	16	69	37	21	0
1977	194	0	0	111	23	29	0
1978	193	0	0	33	14	81	0
1979	204	0	0	95	23	29	0
1980	200	8	0	92	23	70	23
1981	195	0	0	58	31	85	0

*insufficient data

In conclusion, Pleasant Pond maintained mean visibility of 3.2 to 3.7 meters, which indicates moderately high productivity and fair water clarity. Some improvement in visibility occurred after 1976 that cannot be attributed to the restoration project. Phosphorus values are high enough during most of the year to support blue-green algae blooms, yet visibility remains above 2 meters. Additionally, some of the periods of low visibility are not associated with blue-green blooms, but rather with other types of phytoplankton.

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Appendix A

Cost-Benefit Analysis for 5 Hypothetical Manure Management Options (1980)

I. DAILY HAULING FROM A 50-COW STANCHION BARN[1]

Item	CAPITAL COSTS[2]	ANNUAL FIXED COSTS[3]			ANNUAL OPERATING COSTS[3]		TOTAL ANNUAL COSTS
		Deprec.	I.I. H.	Taxes	Repairs	Labor, Tractor time	
Gutter Cleaner System	5000	362	377	-152	300		887
Manure Spreader	3300	304	267	-100	281		752
Manure Loader	2200	203	178	- 66	187		502
Use of Tractor (70 hp) (365 hr. x 7.61)						2778	2778
Daily Labor (365 hr. x 3.35)						1223	1223
Subtotals:	10500	869	822	-318	768	4001	6142
					Value realized from manure:		4003
					Annual Cost:		2139

II. STACKING IN A COVERED CONCRETE PIT, 180 DAY STORAGE FOR A 50-COW STANCHION BARN[1]

Item	CAPITAL COSTS[2]	ANNUAL FIXED COSTS[3]			ANNUAL OPERATING COSTS[3]		TOTAL ANNUAL COSTS
		Deprec.	I.I. H.	Taxes	Repairs	Labor Tractor time	
Manure Pit with Roof	(14500)	725	558	-429	210		1064
Barn Modifications	(500)	25	19	- 10	15		49
Stacker/Thrower	(1750)	161	141	- 68	298		532
Gutter Cleaner System	5000	362	377	-152	300		887
Manure Spreader (200 cf)	3300	239	249	-100	198		586
Manure Loader	(1750)	161	141	- 24	210		488
Tractor Loading (50 hp) 10 hr. x 7.08						71	71
Tractor Hauling (70 hp) 90 hr. x 7.22						650	650
Labor (Spring) 40 hr. x 4.35						174	174
Labor (Summer/Fall) 60 hr. x 3.35						208	208
Subtotals:	45300	1673	1485	-783	1231	1096	4702
Farmer's Cost:	26800				Value realized from manure:		4380
					Annual Cost:		322
Added Costs Due to Storage (farmers share only):	18500				Cost of Daily Hauling:		2139
					Net Annual Savings:		1817

III. DAILY HAULING FROM A 70-COW FREE STALL BARN[1]

Item	CAPITAL COSTS[2]	ANNUAL FIXED COSTS[3]			ANNUAL OPERATING COSTS[3]		TOTAL ANNUAL COSTS
		Deprec.	I.I. H.	Taxes	Repairs	Labor Tractor time	
Push off ramp	1500	75	58	4	23		160
Flail Tank Spreader	5000	461	404	-152	425		1138
Manure Loader/Scraper	3700	341	299	-112	316		844
Tractor Scraping (50 hp) 220 hr. x 6.90						1518	1518
Tractor Loading (50 hp) 91 hr. x 6.90						628	628
Tractor Hauling (70 hp) 274 hr. x 7.61						2085	2085
Labor 585 hr. x 3.35						1960	1960
Subtotals:	10200				764	6955	8333
					Value realized from manure:		5718
					Net Annual Costs:		1216

IV. STACKING IN A COVERED CONCRETE PIT, 180 DAYS FOR A 70-COW FREE STALL BARN[1]

Item	CAPITAL COSTS[2]	ANNUAL FIXED COSTS[3]			ANNUAL OPERATING COSTS[3]		TOTAL ANNUAL COSTS
		Deprec.	I.I. H.	Taxes	Repairs	Labor Tractor time	
Push off ramp, Gravity Drain System	(4800)	240	185	-111	144		458
Concrete Pit w/Roof	(23500)	1175	905	-605	270		1745
Flail Tank Spreader	5000	362	377	-152	300		887
Manure Loader/Scraper	3700	341	299	-112	316		844
Tractor scraping (50 hp) 220 hr. x 6.90						1518	1518
Tractor loading (50 hp) 28 hr. x 6.90						193	193
Tractor hauling (70 hp) 85 hr. x 7.22						614	614
Labor - scraping 220 hr. x 3.35						737	737
Labor - hauling (spring) 54 x 4.35						235	235
Labor - hauling (fall) 75 x 3.35						251	251
Subtotals:	65300				1030	3548	7482
Farmer's Cost:	37000				Value realized from manure:		6257
					Annual Cost:		1225
Added Costs due to Storage (farmer's share only):	26800				Cost of daily hauling:		2615
					Net Annual Savings:		1390

V. EARTHEN MANURE STORAGE BASIN, 365 DAYS FOR A 70-COW FREE STALL BARN[1]

Item	CAPITAL COSTS[2]	ANNUAL FIXED COSTS[3]			ANNUAL OPERATING COSTS[3]		TOTAL ANNUAL COSTS
		Deprec.	I.I. H.	Taxes	Repairs	Labor Tractor time	
Earthen Basin	(7500)	375	289	-100	225		789
Pumping Dock	(1000)	100	77	- 20	130		187
Milkroom Waste Pipeline	(500)	25	38	- 13	15		65
Transfer Pump	(4000)	289	302	-186	400		805
Pump Housing/Barn Mod.	(2500)	125	96	- 67	75		229
Agitator Pump	(1800)	130	136	- 68	216		414
Liquid Manure Spreader (2300 gal.)	(3800)	275	286	- 65	380		876
Tractor Scraper	3700	341	299	-112	316		844
Tractor Scraping (50 hp) 220 hr. x 6.90						1518	1518
Tractor Pumping (70 hp) 50 hr. x 7.22						361	361
Tractor Hauling (70 hp), 92 hr. x 7.22						664	664
Labor - Scraping 220 hr. x 3.35						737	737
Labor - pump, haul, sp-ead (spring) 110 hr. x 4.35						479	479
Subtotals:	41900				1657	3759	7968

Farmer's Cost:	24800	Value realized from manure: 6682
Added Costs due to Storage: (farmer's share only)	16100	Annual Cost : 1286
		Cost of Daily Hauling: 2615
		Net Annual Savings : 1329

FOOTNOTES

[1] A 50-COW farm assumes 40 additional youngstock or 70 animal units.
A 70-COW farm assumes 60 additional youngstock or 100 animal units.

[2] Capital costs are expressed at 1980 market value, and when in parentheses, indicate the capital outlay required by the farmer after federal cost-sharing by EPA. The full cost of these items is included in the subtotal for each case study.

[3] Depreciation: The basis for depreciation is the farmers capital investment. All structures and earthen basins are depreciated using the straight line method over 20 years. Equipment is depreciated using the actual trade-in value method described by N.Y. State Agricultural Engineering Extension Bulletin 431 (1978) "Selecting Field Machinery-Estimating Cost".

I,I,H: Interest, Insurance and Housing: the basis for calculation of these costs is the farmer's capital investment. For equipment, a composite percentage rate of 14% (12% interest on loans, ½% insurance, and 1½% housing) multiplied by the average value of the equipment over its useful life yields the interest, insurance and housing cost per year. Average value is calculated using N.Y. State Agricultural Engineering Extension Bulletin 431. For structures, this column represents the interest cost of borrowing the required capital investment at 12% for 10 years, amortized over 20 years.

Taxes: Includes property and income tax.

Property Tax: In Maine, all equipment and structures used exclusively for pollution control are exempted from property tax. All other equipment mentioned in this analysis is subject to personal property tax. This is calculated as ½ actual purchase price (average over useful life) x .025 (25 mils).

Federal Tax: This indicates the dollars saved over the useful life of the structure or equipment due to tax deductions such as depreciation, investment credit, conservation expense, and interest, using tax laws applicable to 1980. Each case has been computed individually and includes all federal grants as income. The affect of these grants and deductions (computed on actual costs, not just farmers cost) on social security tax is included in the analysis.

Repairs: Repair costs are computed using N.Y. State Agricultural Engineering Extension Bulletin 431 repair cost curves which vary according to type and amount of useage.
For manure spreaders, stackers, and front-end loaders/scrapers used daily (useful life of 7 years), average annual repair costs are computed as 8.5% of the actual purchase price.
For manure spreaders, front-end loaders, and agitation pumps used only in the spring-fall period and gutter cleaners (useful life of 10 years) the average annual repair cost is 6% of actual purchase price.
A rate of 5% is used for repair costs on transfer pumps, while 1.5% is used for repair costs of all structures (calculated only on the roof portion of the concrete pits).

Labor and Tractor Operating Use Rates: Hourly tractor use rates were computed using N.Y. State Agricultural Engineering Extension Bulletin 431 (1978). Labor rates reflect the minimum wage effective January 1981: $3.35/hr., except labor during the busy spring period is valued higher at $4.35/hr.

Appendix B

Description of Farm Projects Constructed

Under the Cobbossee Watershed Lakes

Restoration Project 1978-81

Type Farm	System Components	$ Cost, (Year Complete)
ANNABESSACOOK LAKE DRAINAGE		
DAIRY	Concrete structure	
90 a.u. stanchion	40' x 80' x 10'	$23,032.86
	Roof	10,479.38
	Shed for stacker	1,200.00
	Equipment & installation	8,923.18
	Earthwork	3,619.60
		$47,255.02
		(1978)
DAIRY	Concrete structure	
55 a.u. stanchion	45' x 45' x 10'	$14,555.32
	Roof and shed	9,100.36
	Equipment & installation	3,989.61
	Earthwork	4,948.95
		$32,593.94
		(1979)
DAIRY	Concrete structure	
110 a.u. freestall	50' x 80' x 10'	$22,081.31
	Roof	9,061.96
	Earthwork	3,956.27
	Transfer system	5,051.80
	Equipment	7,836.00
		$44,987.34
		(1978)
POULTRY	Concrete slab	
44,000 birds	40' x 40'	$ 3,019.06
broilers	Earthwork	3,063.50
		$ 6,082.56
		(1978)

COBBOSSEE LAKE DRAINAGE

DAIRY 38 a.u. stanchion	Concrete headwall	$ 4,651.75
	Asphalt pad 40' x 40'	1,214.40
	Earthwork	3,441.63
	Equipment	4,349.00
		$13,656.78
		(1979)
DAIRY 87 a.u. freestall	Concrete structure 45' x 75' x 10'	
	constructed with own funds	unknown
		(1978)
SWINE 60 sows & feeder pigs	Subgrade concrete pit 100' x 10' x 6'	$10,275.58
	Earthwork	6,578.00
	Floor slats	3,560.00
	Barn jacking/moving	8,750.00
	Equipment	8,219.30
		$37,382.88
		(1978)
DAIRY 33 a.u. stanchion	Concrete structure (precast) 8' x 35' x 45'	$ 5,900.00
	Earthwork	2,200.00
		$ 8,100.00
		(1981)
DAIRY 68 a.u. stanchion	Concrete structure 40' x 46' x 6'	$ 7,134.00
	Earthwork	1,463.66
	Runoff controls	841.00
	Equipment	2,912.66
		$12,351.32
		(1978-79)
DAIRY 100 a.u. freestall	Precast concrete tank 100' x 100' x 8'	$25,600.00
	Earthwork	18,932.08
	Gravity transfer & milkroom hook-up	9,732.96
	Equipment	10,845.00
		$65,110.04
		(1980)
DAIRY 75 a.u. stanchion	Concrete structure (precast) 50' x 70' x 8'	$15,684.40
	Earthwork & barnyard drainage	8,758.00
	Equipment	11,365.00
	Barn Modifications	10,899.93
		$46,707.33
		(1980)

DAIRY	Concrete pad #1	
100 a.u. stanchion	60' x 90' x 6" w/ precast end wall	$ 5,323.02
(2 facilities)	Earthwork	1,971.50
		$ 7,294.52
		(1980)
	Concrete pad #2	
	50' x 70' x 6" w/ 50' x 4' end wall	$ 2,877.59
	Earthwork	1,319.00
	Equipment	3,629.00
		$ 7,825.59
		(1980)
SWINE	Earthen lagoon	$ 4,512.50
50 sows & feeder	Barn modification/pumping dock	3,331.91
pigs	Equipment	2,434.09
		$10,278.52
		(1979)
POULTRY	Concrete structure	
58,000 birds	20' x 32' x 6'	$ 4,168.59
broilers	Earthwork	2,135.75
(2 facilities)	Roof	2,433.05
		$ 8,737.38
		(1978)
	Asphalt Pad 42' x 52'	$ 2,150.00
	Earthwork (berms)	4,893.25
	Diversion	2,892.50
		$ 9,935.75
		(1979)
POULTRY	Concrete structure	
6,000 birds	40' x 40' x 4'	$ 5,253.46
replacement hens	Earthwork	1,474.08
		$ 6,727.54
		(1978)

PLEASANT POND DRAINAGE

DAIRY	Concrete structure	
60 a.u. stanchion	40' x 68' x 8'	$16,978.00
	Earthwork	2,675.00
	Barn modifications	851.82
	Equipment	7,324.00
		$27,828.82
		(1980)
BEEF	Concrete structure	
18 a.u.	20' x 35' x 6'	$ 4,153.39
loose housing	Roof & 4' wall extensions	4,125.99
	Earthwork	2,339.10
		$10,618.48
		(1979)

DAIRY REPLACEMENTS	Concrete structure	
20 a.u. stanchion	20' x 55' x 4'	$ 5.469.60
	Barn Modifications	899.27
	Earthwork	1.460.75
		$ 7.829.62
		(1978)
DAIRY	Concrete structure	
35 a.u. stanchion	38' x 50' x 5'	$ 7.530.84
	Earthwork	1.350.25
		$ 8.881.09
		(1978)
DAIRY	Concrete structure	
65 a.u. stanchion	45' x 70' x 8'	$13.578.14
	Earthwork	4.429.50
		$18,007.64
		(1981)
BEEFALO	Asphalt pad 36' x 100'	$ 3,000.00
25 a.u.	Earthwork	9.190.00
loose housing		$12,190.00
		(1979)
DAIRY	Concrete structure	
45 a.u. stanchion	40' x 55' x 8'	$12.704.50
	Roof	6.165.00
	Earthwork	2.861.85
		$21.731.40
		(1979)
DAIRY	Concrete structure	
40 heifers	37' x 37' x 4'	$ 4.124.19
stanchion	Earthwork	1.461.25
	Runoff controls including	
	450' diversion & asphalted barnyard	$ 3.361.64
		$ 8.947 09
		(1978)
DAIRY REPLACEMENTS	Concrete structure	
30 a.u.	25' x 66' x 4'	$10.348.51
loose housing	Earthwork	3.208.75
	Asphalted diversion	4.300.00
		$17.857.26
		(1979)
DAIRY	Concrete structure	
105 a.u. stanchion	60' x 100' x 6'	$20.491.87
	Transfer pump & house	13.341.05
	Earthwork	3,479.00
	Barn modification	2.104.34
	Equipment	8.423.00
		$47.839.23
		(1979)

POULTRY 42,000 birds broilers	Concrete structure (precast) 40' x 45' x 8' Earthwork	$ 9,795.00 3,085.00 $12,880.00 (1979)
POULTRY 20,000 birds broilers (2 facilities)	Concrete pad 40' x 40' x 6" Earthwork	$ 2,891.00 3,093.14 $ 5,984.14 (1978)
	Concrete structure 30' x 40' x 4' Roof & 4' wall extensions Earthwork	$ 5,329.72 4,738.43 1,696.07 $11,764.22 (1979)
POULTRY 43,000 birds broilers	Concrete structure 50' x 50' x 8' Earthwork	$11,733.47 3,050.00 $14,783.47 (1979)
POULTRY 30,000 birds broilers	Concrete structure 38' x 40' x 5' Roof & 4' wall extensions Earthwork Equipment	$ 4,996.15 7,620.99 1,231.25 384.25 $14,232.64 (1978)

Appendix C Annabessacook Lake Water Quality Data

Table 1C: Annabessacook Lake Phosphorus

1981 ANNABESSACOOK LAKE PHOSPHORUS

	South		North		Whole Lake	
	Kg P	P,ppb	Kg P	P,ppb	Kg P	P,ppb
3/26					616.5	21.0
4/22	524.8	20.9	71.8	15.8	596.7	20.1
5/26	437.7	17.5	86.6	19.0	524.3	17.7
6/19	505.7	20.2	87.0	19.1	592.7	20.0
7/15	676.5	26.9	121.2	26.5	797.7	26.8
8/05	799.0	31.7	119.4	26.0	918.4	30.8
8/21	919.7	36.4	120[e]	26[e]	1039.7[e]	34.8[e]
8/31	857.3	34.2	118.4	26.0	975.7	33.0
9/21	927.6	37.7	134.6	30.4	1062.2	36.6
10/09	825.3	32.7	128.9	28.1	954.2	32.0
11/19	607.9	23.8	61.7	13.2	669.6	22.1

[e] estimated for north end

1980 ANNABESSACOOK LAKE PHOSPHORUS

	KGP	vol. wtd. ppb P
1/21	410.4	14.8
2/20	398.1	15.1
3/26	407.6	13.5
4/14	809.5	26.2
5/05	632.0	20.5
6/06	658.1	22.2
6/19	596.7	20.1
7/10	626.3	21.1
7/23	733.1	24.9
8/07	822.7	27.9
8/22	1026.0	34.8
9/03	1045.1	35.4
9/17	1018.7	34.6
10/08	859.1	30.9
11/04	614.6	22.9

Table 1C (cont.)

1979 ANNABESSACOOK LAKE PHOSPHORUS

	South		North		Whole Lake	
	Kg P	P,ppb	Kg P	P,ppb	Kg P	P,ppb
1/24	456.9	18.3	76.5	16.9	533.4	18.1
2/28	375.3	15.0	53.1	11.8	428.4	14.5
3/16						
4/20	378.3	15.2	68.8	15.2	447.1	15.2
5/02	454.6	18.2	306.3	67.8	760.9	25.8
5/15	441.8	17.7	53.4	11.8	495.2	16.8
5/31	496.6	19.9	87.1	19.3	583.8	19.8
6/12	449.4	18.0	84.9	18.8	534.3	18.1
6/20	523.2	21.1				
6/27	515.6	20.7	84.5	18.7	600.1	20.4
7/12	518.5	20.8	75.7	16.7	594.2	20.2
7/25	540.2	21.6	101.7	22.5	641.8	21.8
8/02	761.0	30.5	120.4	26.6	881.5	29.9
8/09	858.4	34.4	167.3	37.0	1025.8	34.8
8/14	857.5	34.4	174.8	38.7	1032.4	35.0
8/21	853.3	34.2	153.1	33.9	1006.3	34.1
8/30	781.7	31.3	119.9	26.3	901.6	30.6
9/05	726.4	29.1	116.9	25.9	843.3	28.6
9/12	824.2	33.0	131.4	29.1	955.6	32.4
9/20	706.6	28.3	107.5	23.8	814.1	27.6
9/26	644.4	25.8	96.2	21.3	740.6	25.1
10/03	457.1	18.3	92.5	20.5	549.6	18.6
10/16	632.1	25.3	104.1	23.0	736.2	25.0
10/30	603.6	24.2	98.1	21.7	701.7	23.8
11/15	599.2	24.0	76.8	17.0	676.0	22.9

Table 1C (cont.)

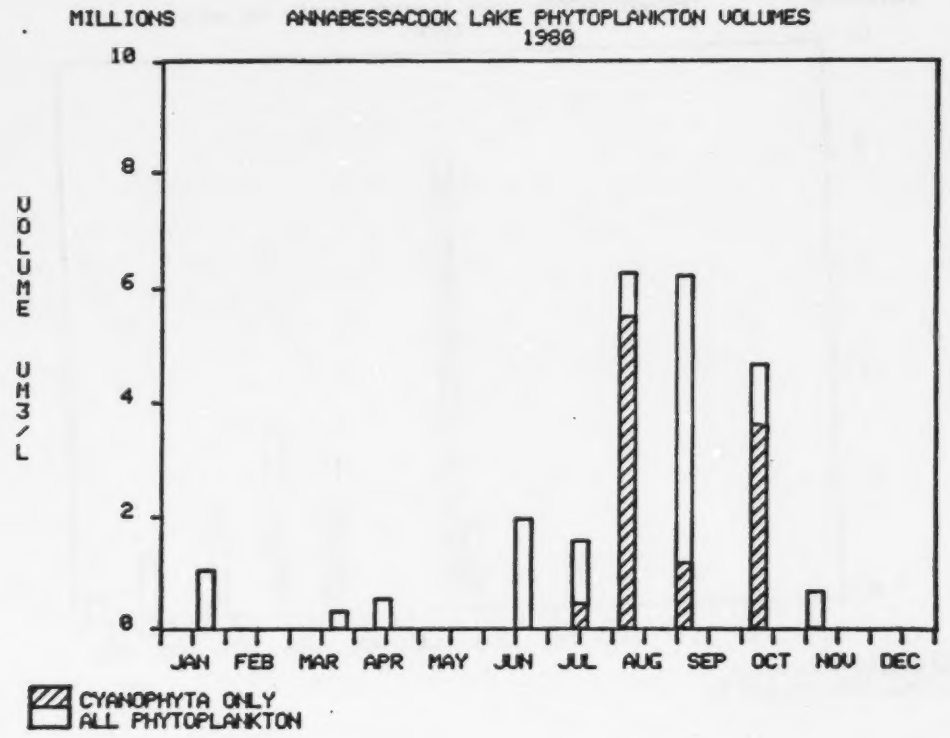
1978 ANNABESSACOOK LAKE PHOSPHORUS

	KGP	vol. wtd. ppb P
1/03	413	14.0
2/09	370	12.6
3/20	495	16.8
6/06	650	22.0
6/23	672	22.8
7/14	1008	34.2
7/21	1128	38.3
7/31	1460	49.5
8/07	1349	45.8
8/30	1174	39.8
9/13	1046	35.5
9/25	824	28.0
10/03	1133	38.4
10/21	883	30.0
11/07	810	27.5
11/27	715	24.3
12/27	557	18.9

1977 ANNABESSACOOK LAKE PHOSPHORUS

	KGP	vol. wtd. ppb P
5/05	503	17.1
5/26	588	20.0
6/10	699	23.7
6/23	789	26.8
7/11	1028	34.9
7/21	1292	43.8
8/02	1542	52.3
8/09	1420	48.2
8/16	1672	56.7
8/24	1807	61.3
8/31	1806	61.3
9/12	2239	76.0
9/20	1993	67.6
9/23	1726	58.6
9/26	1745	59.2
9/30	1644	55.8
10/10	1046	35.5
11/03	811	27.5

Figure 1C: Annual Phytoplankton Volumes, Annabessacook Lake



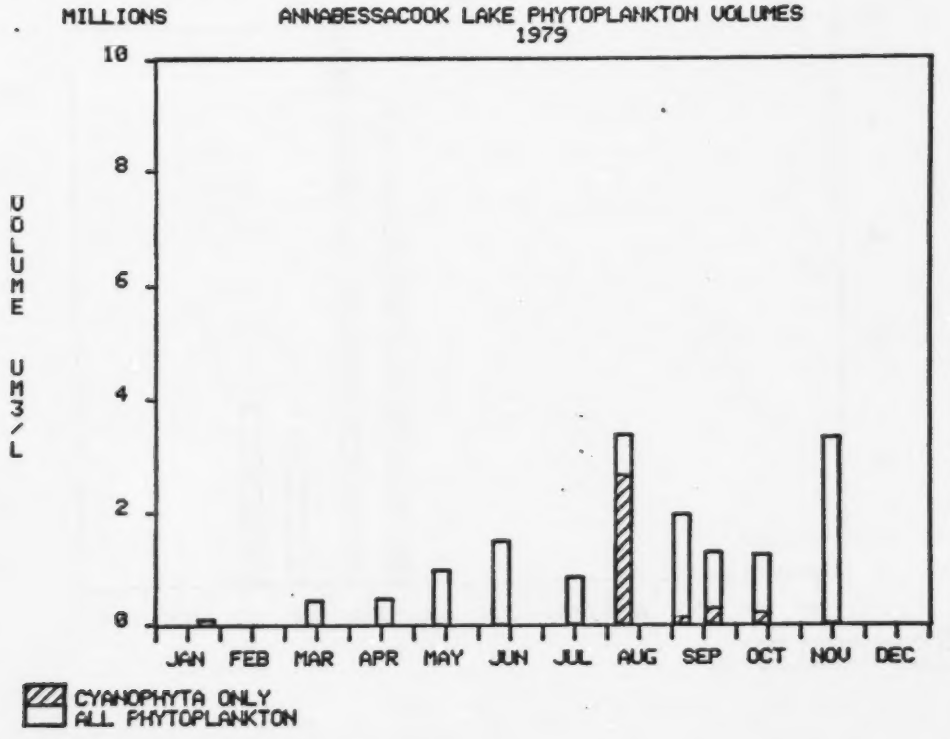
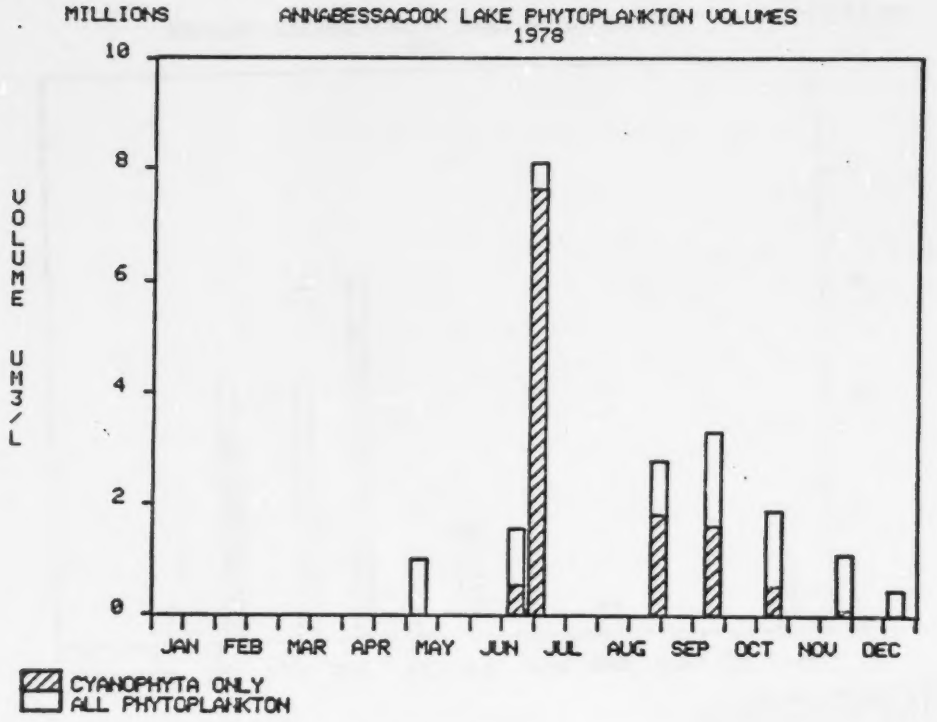


Figure 1C (cont.)



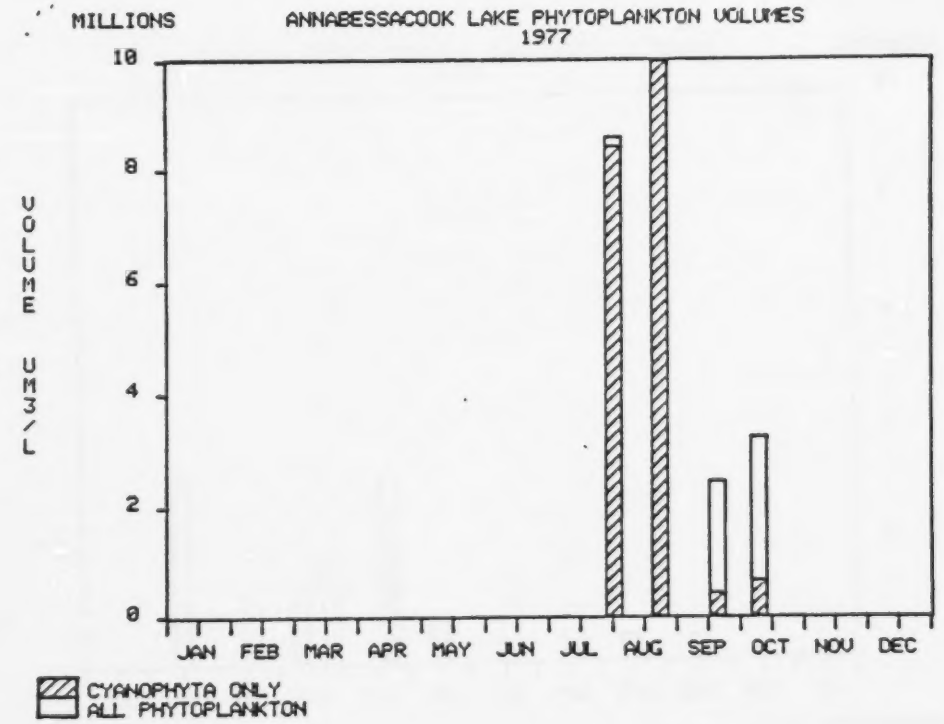
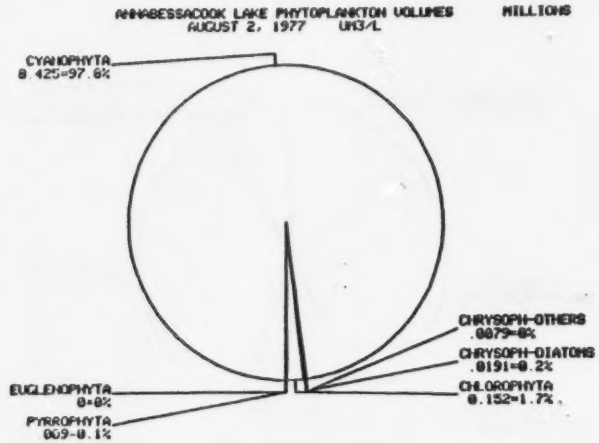
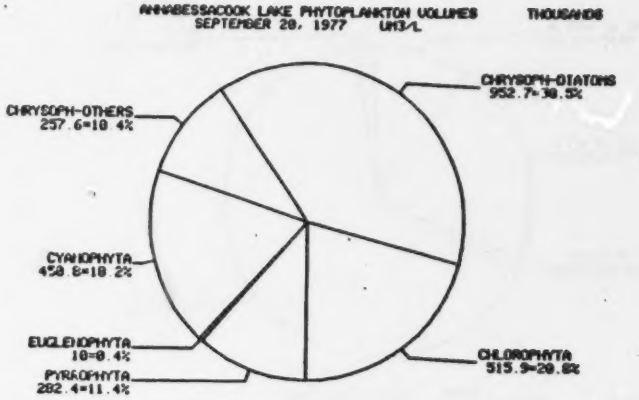
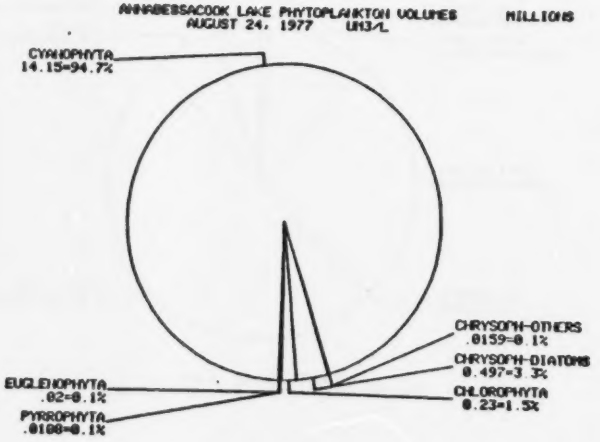
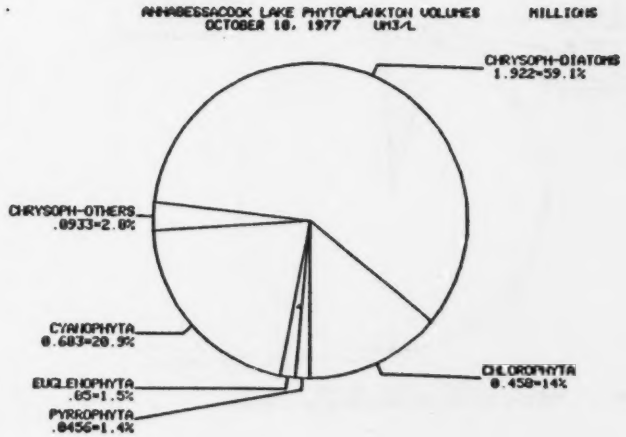


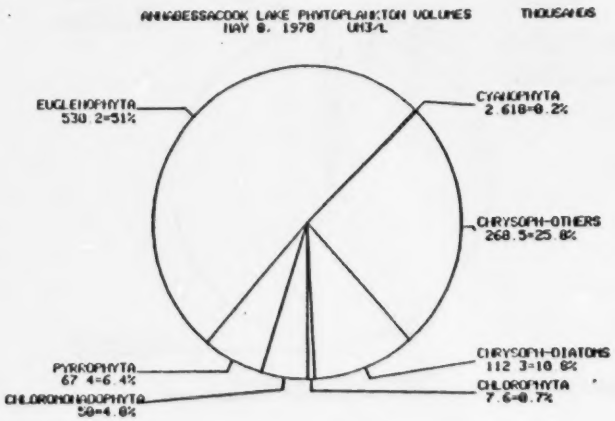
Figure 2C: Daily Phytoplankton Volumes, Annabessacook Lake

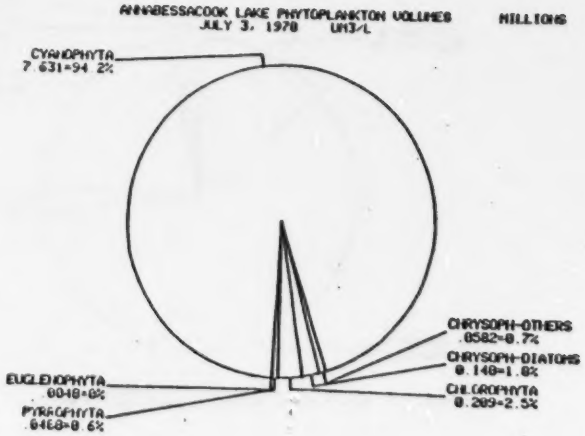


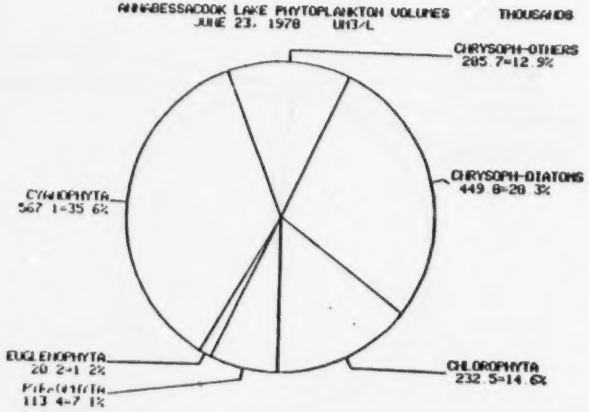


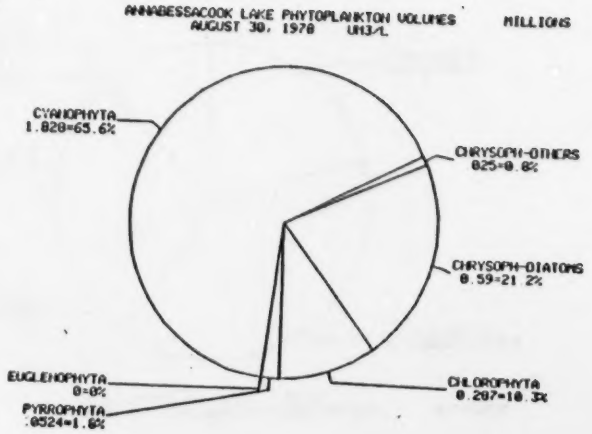


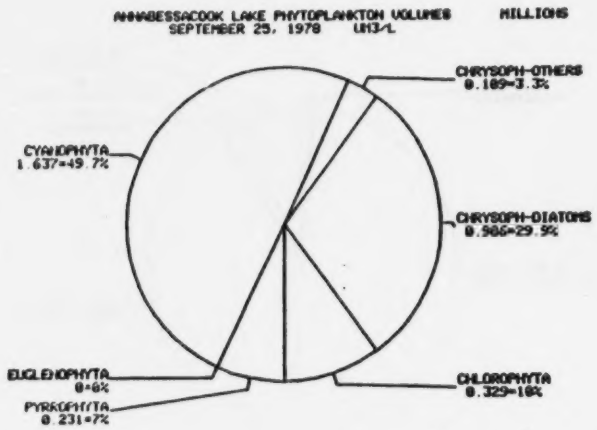


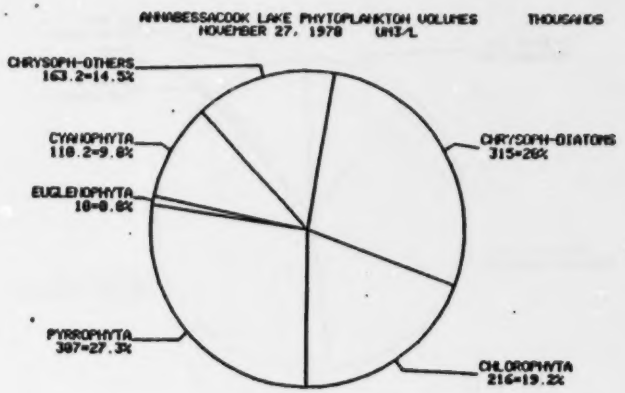

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
MAY 8, 1978 UM3/L
EUGLENOPHYTA
530.2=51%
CYANOPHYTA
2.618=0.2%
CHRYSOPH-OTHERS
268.5=25.8%
CHRYSOPH-DIATOMS
112.3=10.8%
CHLOROPHYTA
7.6=0.7%
PYRROPHYTA
67.4=6.4%
CHLOROMONADOPHYTA
50=4.8%

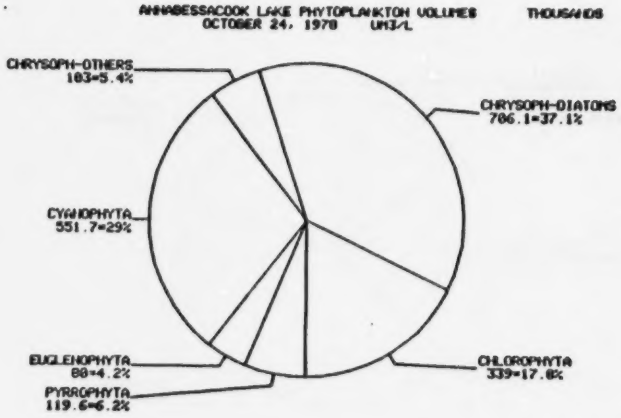

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES MILLIONS
JULY 3, 1978 UM3/L
CYANOPHYTA
7.631=94.2%
CHRYSOPH-OTHERS
.0582=0.7%
CHRYSOPH-DIATOMS
0.140=1.8%
CHLOROPHYTA
0.209=2.5%
EUGLENOPHYTA
.0048=0%
PYRROPHYTA
.0468=0.6%

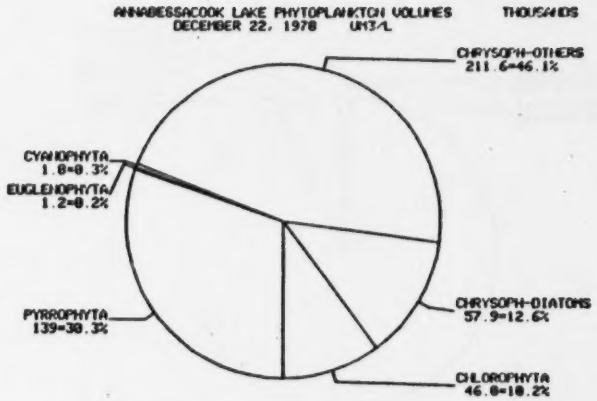

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
JUNE 23, 1978 UM3/L
CHRYSOPH-OTHERS
205.7=12.9%
CHRYSOPH-DIATOMS
449.8=28.3%
CYANOPHYTA
567.1=35.6%
EUGLENOPHYTA
20.2=1.2%
CHLOROPHYTA
232.5=14.6%

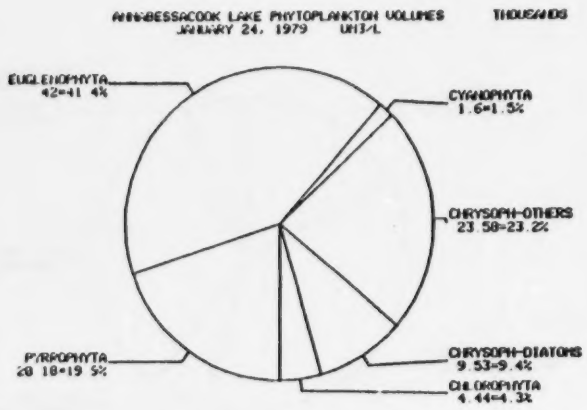

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES MILLIONS
AUGUST 30, 1978 UM3/L
CYANOPHYTA
1.828=65.6%
CHRYSOPH-OTHERS
025=0.8%
CHRYSOPH-DIATOMS
0.59=21.2%
CHLOROPHYTA
0.287=10.3%
EUGLENOPHYTA
0=0%
PYRROPHYTA
.0524=1.8%

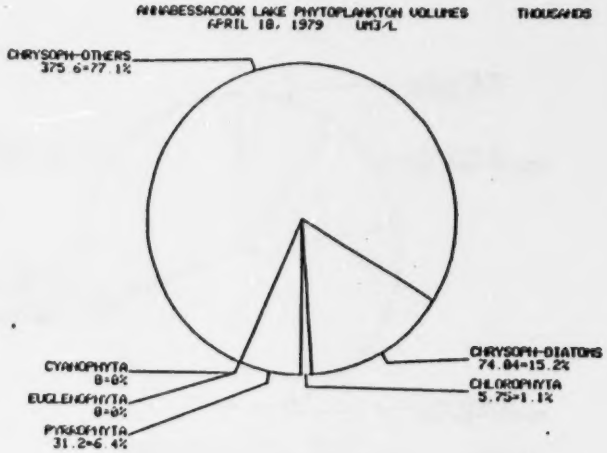

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES MILLIONS
SEPTEMBER 25, 1978 UM3/L
CHRYSOPH-OTHERS
0.109=3.3%
CYANOPHYTA
1.637=49.7%
CHRYSOPH-DIATOMS
0.986=29.9%
EUGLENOPHYTA
0=0%
CHLOROPHYTA
0.329=10%
PYRROPHYTA
0.231=7%

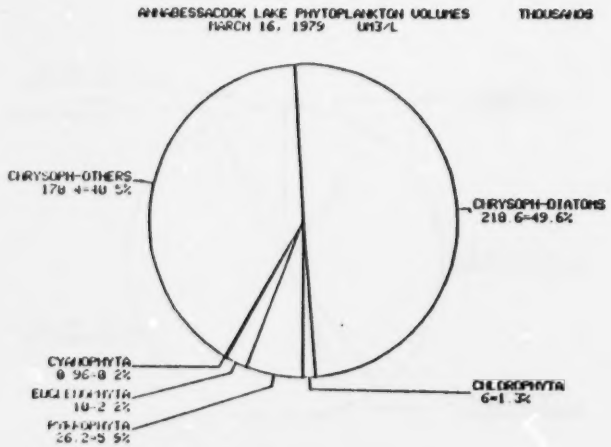

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
NOVEMBER 27, 1978 UM3/L
CHRYSOPH-OTHERS
163.2=14.5%
CYANOPHYTA
110.2=9.8%
CHRYSOPH-DIATOMS
315=28%
EUGLENOPHYTA
10=0.8%
PYRROPHYTA
307=27.3%
CHLOROPHYTA
216=19.2%

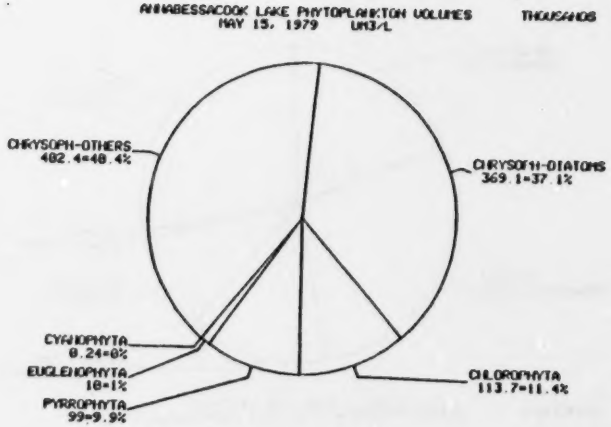

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
OCTOBER 24, 1978 UM3/L
CHRYSOPH-OTHERS
103=5.4%
CHRYSOPH-DIATOMS
706.1=37.1%
CYANOPHYTA
551.7=29%
EUGLENOPHYTA
80=4.2%
CHLOROPHYTA
339=17.8%
PYRROPHYTA
119.6=6.2%

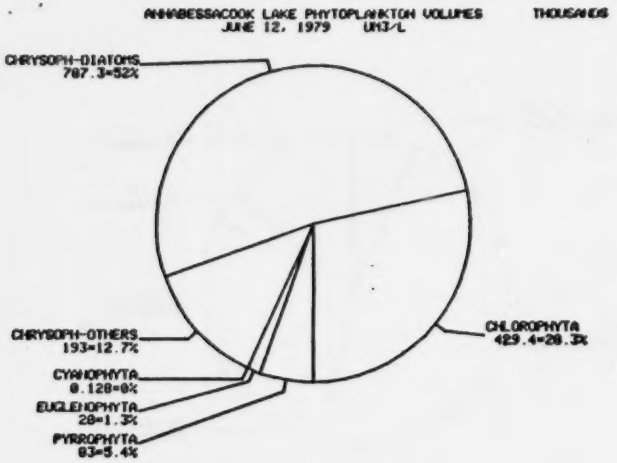

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
DECEMBER 22, 1978 UM3/L
CHRYSOPH-OTHERS
211.6=46.1%
CYANOPHYTA
1.8=0.3%
EUGLENOPHYTA
1.2=0.2%
PYRROPHYTA
139=30.3%
CHRYSOPH-DIATOMS
57.9=12.6%
CHLOROPHYTA
46.8=10.2%

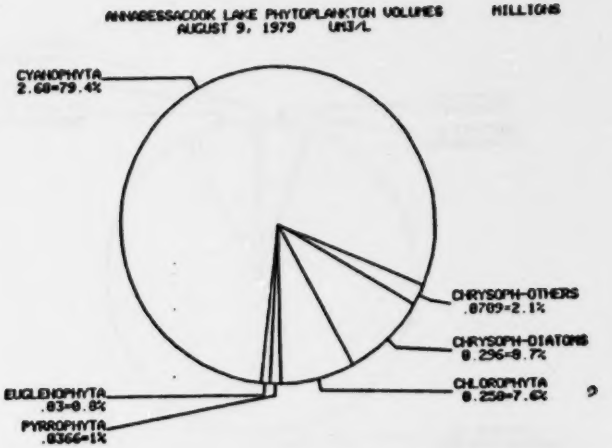

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
JANUARY 24, 1979 UM3/L
EUGLENOPHYTA
42=41.4%
CYANOPHYTA
1.6=1.5%
CHRYSOPH-OTHERS
23.58=23.2%
CHRYSOPH-DIATOMS
9.53=9.4%
CHLOROPHYTA
4.44=4.3%
PYRROPHYTA
20.18=19.5%

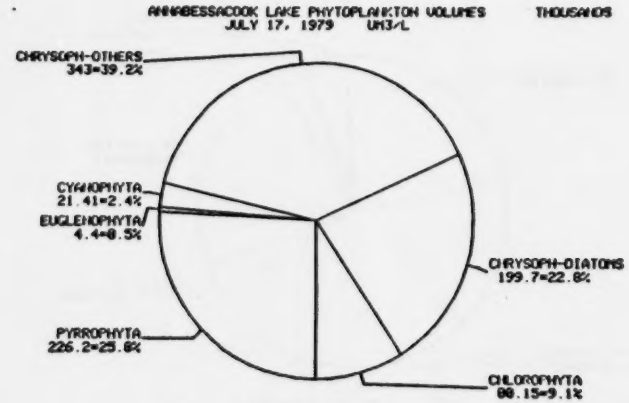

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
APRIL 18, 1979 UM3/L
CHRYSOPH-OTHERS
375.6=77.1%
CHRYSOPH-DIATOMS
74.04=15.2%
CHLOROPHYTA
5.75=1.1%
CYANOPHYTA
0=0%
EUGLENOPHYTA
0=0%
PYRROPHYTA
31.2=6.4%

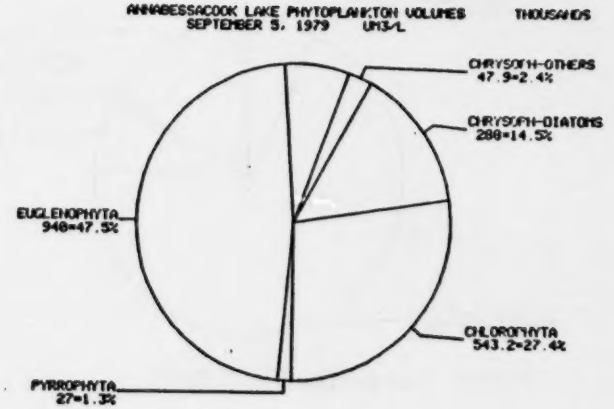

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
MARCH 16, 1979 UM3/L
CHRYSOPH-OTHERS
170.4=40.5%
CHRYSOPH-DIATOMS
218.6=49.6%
CYANOPHYTA
0.96=0.2%
CHLOROPHYTA
6=1.3%

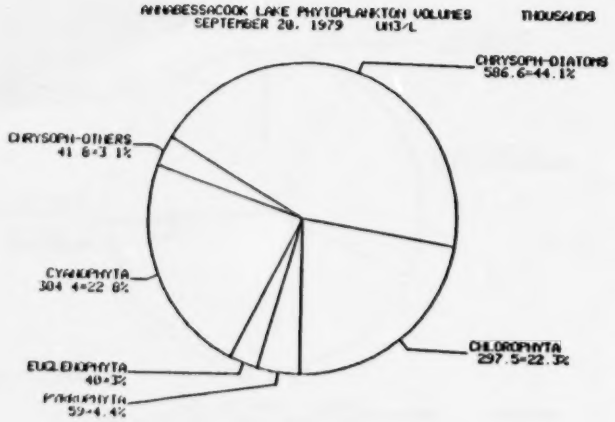

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
MAY 15, 1979 UM3/L
CHRYSOPH-OTHERS
402.4=48.4%
CHRYSOPH-DIATOMS
369.1=37.1%
CYANOPHYTA
0.24=0%
EUGLENOPHYTA
18=1%
PYRROPHYTA
99=9.9%
CHLOROPHYTA
113.7=11.4%

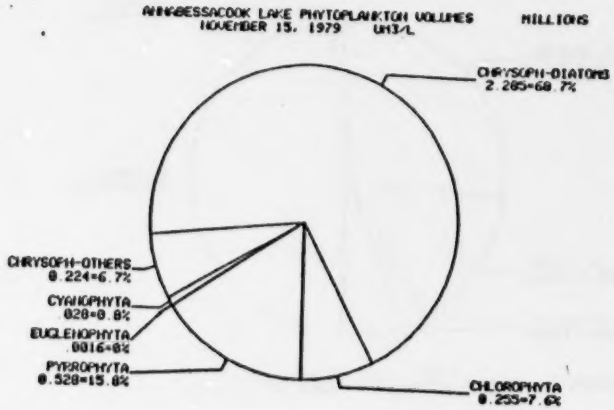

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
JUNE 12, 1979 UM3/L
CHRYSOPH-DIATOMS
787.3=52%
CHRYSOPH-OTHERS
193=12.7%
CYANOPHYTA
0.128=0%
EUGLENOPHYTA
20=1.3%
PYRROPHYTA
83=5.4%
CHLOROPHYTA
429.4=28.3%

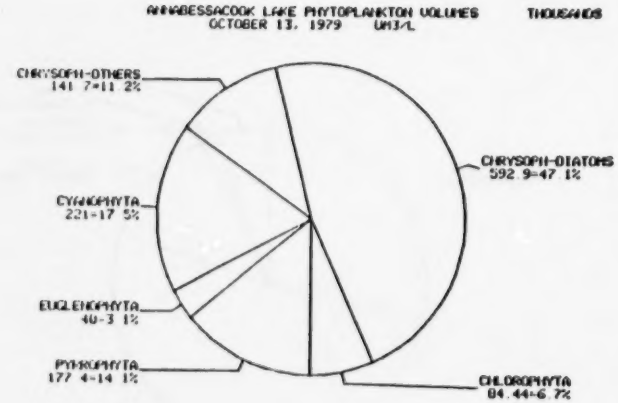

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES MILLIONS
AUGUST 9, 1979 UM3/L
CYANOPHYTA
2.68=79.4%
CHRYSOPH-OTHERS
.0709=2.1%
CHRYSOPH-DIATOMS
0.256=8.7%
CHLOROPHYTA
0.258=7.6%
EUGLENOPHYTA
.03=0.8%
PYRROPHYTA
.0366=1%

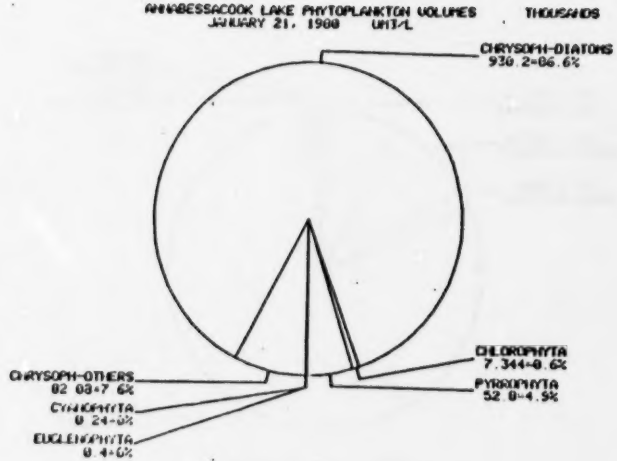

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
JULY 17, 1979 UM3/L
CHRYSOPH-OTHERS
343=39.2%
CYANOPHYTA
21.41=2.4%
EUGLENOPHYTA
4.4=0.5%
CHRYSOPH-DIATOMS
199.7=22.8%
PYRROPHYTA
226.2=25.8%
CHLOROPHYTA
80.15=9.1%

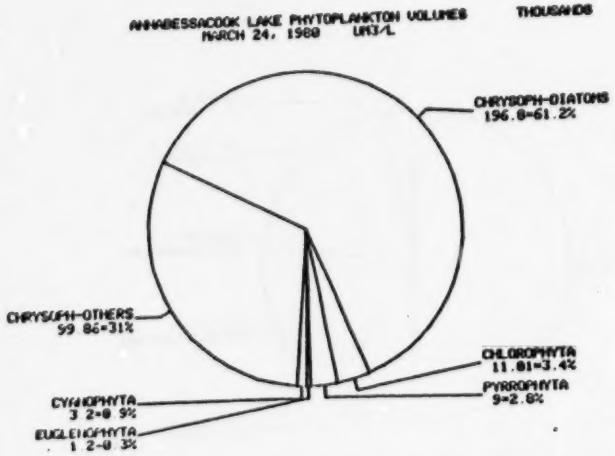

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
SEPTEMBER 5, 1979 UM3/L
CHRYSOPH-OTHERS
47.9=2.4%
CHRYSOPH-DIATOMS
288=14.5%
EUGLENOPHYTA
948=47.5%
CHLOROPHYTA
543.2=27.4%
PYRROPHYTA
27=1.3%

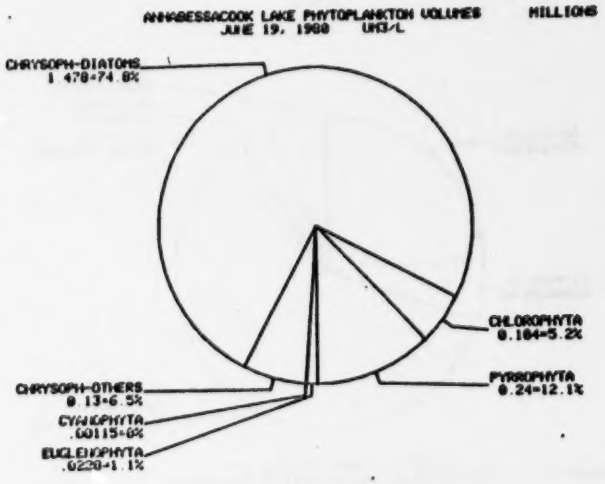

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
SEPTEMBER 20, 1979 UM3/L
CHRYSOPH-DIATOMS
586.6=44.1%
CHRYSOPH-OTHERS
41.8=3.1%
CYANOPHYTA
304.4=22.8%
CHLOROPHYTA
297.5=22.3%
EUGLENOPHYTA
40=3%
PYRROPHYTA
59=4.4%

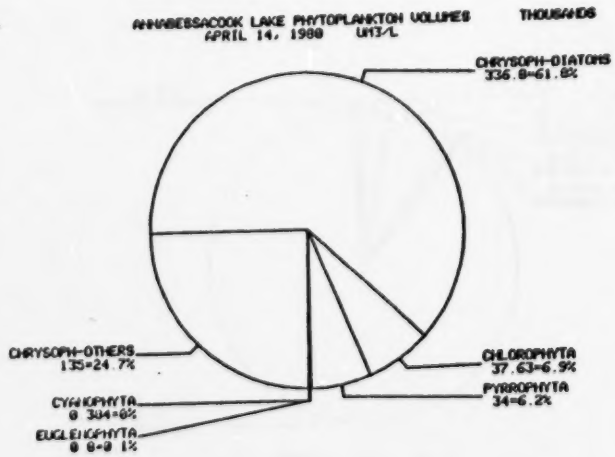

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES MILLIONS
NOVEMBER 15, 1979 UM3/L
CHRYSOPH-DIATOMS
2.285=68.7%
CHRYSOPH-OTHERS
0.224=6.7%
CYANOPHYTA
.028=0.8%
EUGLENOPHYTA
.0016=0%
PYRROPHYTA
0.528=15.8%
CHLOROPHYTA
0.255=7.6%

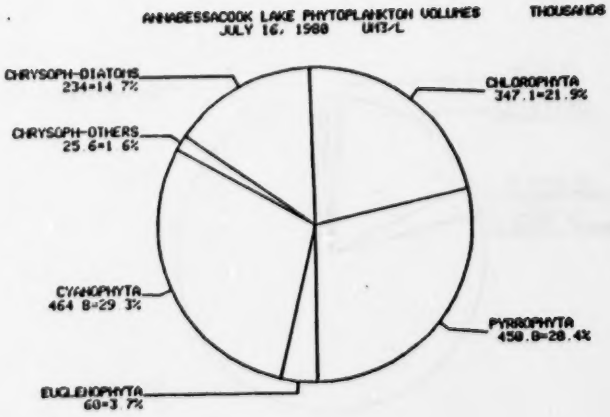

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
OCTOBER 13, 1979 UM3/L
CHRYSOPH-OTHERS
141.7=11.2%
CHRYSOPH-DIATOMS
592.9=47.1%
CYANOPHYTA
221=17.5%
EUGLENOPHYTA
40=3.1%
PYRROPHYTA
177.4=14.1%
CHLOROPHYTA
84.44=6.7%

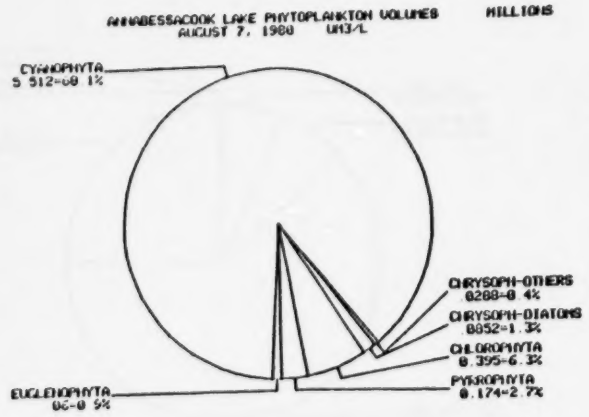

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
JANUARY 21, 1980 UM3/L
CHRYSOPH-DIATOMS
930.2=86.6%
CHLOROPHYTA
7.344=0.6%
PYRROPHYTA
52.8=4.5%
CHRYSOPH-OTHERS
82.08=7.6%
CYANOPHYTA
0.24=0%
EUGLENOPHYTA
0.4=0%

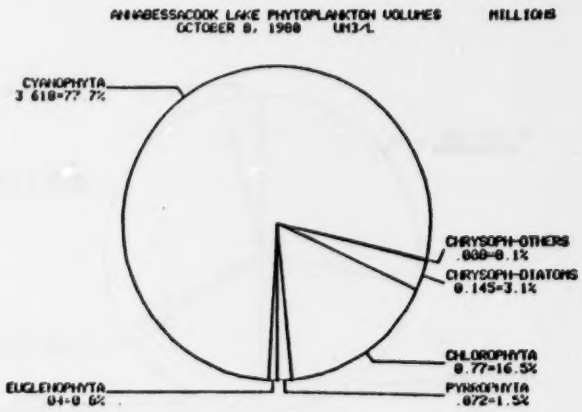

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
MARCH 24, 1988 UM3/L
CHRYSOPH-DIATOMS
196.8=61.2%
CHRYSOPH-OTHERS
99 86=31%
CHLOROPHYTA
11.81=3.4%
PYRROPHYTA
9=2.8%
CYANOPHYTA
3 2=0 9%
EUGLENOPHYTA
1 2=0 3%

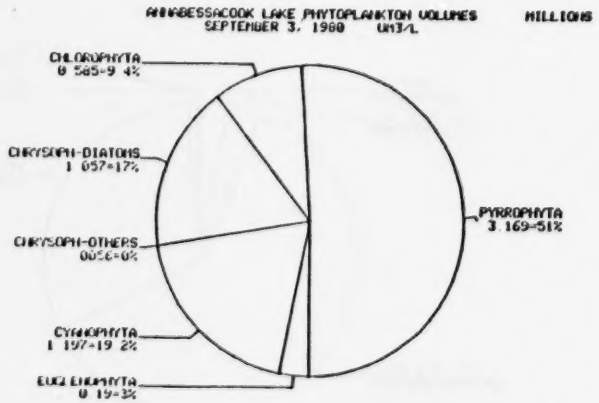

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES MILLIONS
JUNE 19, 1988 UM3/L
CHRYSOPH-DIATOMS
1 478=74 8%
CHLOROPHYTA
0.184=5.2%
PYRROPHYTA
0.24=12.1%
CHRYSOPH-OTHERS
0 13=6 5%
CYANOPHYTA
.00115=0%
EUGLENOPHYTA
.0220=1 1%


ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
APRIL 14, 1988 UM3/L
CHRYSOPH-DIATOMS
336.8=61.8%
CHRYSOPH-OTHERS
135=24 7%
CHLOROPHYTA
37.63=6.9%
PYRROPHYTA
34=6.2%
CYANOPHYTA
0 304=0%
EUGLENOPHYTA
0 8=0 1%


ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
JULY 16, 1988 UM3/L
CHRYSOPH-DIATOMS
234=14 7%
CHLOROPHYTA
347.1=21.9%
CHRYSOPH-OTHERS
25 6=1 6%
CYANOPHYTA
464 8=29 3%
PYRROPHYTA
450.8=28.4%
EUGLENOPHYTA
60=3 7%


ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES MILLIONS
AUGUST 7, 1980 UM3/L
CYANOPHYTA
5 512=88 1%
CHRYSOPH-OTHERS
0288=0 4%
CHRYSOPH-DIATOMS
0852=1 3%
CHLOROPHYTA
0 395=6 3%
PYRROPHYTA
0 174=2 7%
EUGLENOPHYTA
06=0 9%


ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES MILLIONS
OCTOBER 8, 1980 UM3/L
CYANOPHYTA
3 618=77 7%
CHRYSOPH-OTHERS
.008=0.1%
CHRYSOPH-DIATOMS
0.145=3.1%
CHLOROPHYTA
0.77=16.5%
EUGLENOPHYTA
04=0 8%
PYRROPHYTA
.072=1.5%


ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES MILLIONS
SEPTEMBER 3, 1980 UM3/L
CHLOROPHYTA
0 585=9 4%
CHRYSOPH-DIATOMS
1 057=17%
CHRYSOPH-OTHERS
0056=0%
CYANOPHYTA
1 197=19 2%
EUGLENOPHYTA
0 19=3%
PYRROPHYTA
3 169=51%

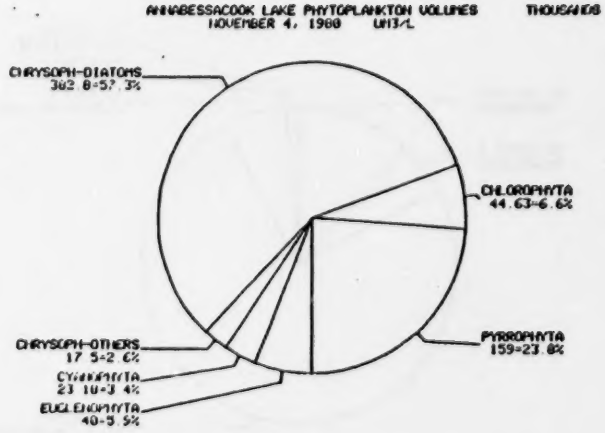

ANNABESSACOOK LAKE PHYTOPLANKTON VOLUMES THOUSANDS
NOVEMBER 4, 1980 UM3/L
CHRYSOPH-DIATOMS
362 8=57 3%
CHLOROPHYTA
44 63=6 6%
PYRROPHYTA
159=23 8%
CHRYSOPH-OTHERS
17 5=2 6%
CYANOPHYTA
23 10=3 4%
EUGLENOPHYTA
40=5 5%

Table 2C: Annabessacook Lake Chlorophyll-a (South basin)

1981			1980			1979			1978			1977		
date	ug/l	type	date	ug/l	type	date	ug/l	type	date	ug/l	type	date	ug/l	type
3/19	8.25	10mC	1/21	4.22	10mC	1/24	2.03	5mC	1/03	3.7	2mG	5/05	15.65	C
4/22	7.20	10mC	2/20	5.77	10mC	2/28	3.81	5mC	2/09	2.0	3mG	5/26	7.42	C
5/26	3.48	10mC	3/26	6.08	10mC	3/16	3.54	5mC		1.0	5mG	6/10	9.42	C
6/19	2.9	10mC	4/14	9.29	10mC	4/18	3.68	10mC	3/20	1.7	3mG	6/23	13.51	C
7/15	12.0	6mC	4/22	6.28	10mC	4/20	4.7	10mC	6/06	6.1	5mC	7/11	9.72	C
8/05	14.8	7mC	5/05	5.97	10mC	5/02	5.8	10mC	6/23	6.4	5mC	7/21	17.32	10mC
8/21	16.1	7mC	5/15	5.33	10mC	5/15	5.27	10mC	7/03	18.6	5mC		27.65	epiC
8/31	16.4	8mC	6/06	4.47	10mC	5/31	3.06	10mC	7/14	29.1	5mC	8/02	58.28	1mG
9/17	42.8	8mC	6/19	4.2	10mC	6/12	4.26	10mC	7/21	41.6	5mC		5.05	7mG
10/09	23.9	10mC	6/25	4.5	7mC	6/20	4.48	10mC	7/31	27.9	5mC	8/09	13.71	2mG
11/19	6.2	10mC	7/10	4.16	8mC	6/27	5.28	7mC	8/07	36.8	3mG		3.61	5mG
			7/16	6.16	8mC	7/03	4.48	7mC		31.1	6mG	9/15	15.65	
			7/23	8.86	8mC	7/12	4.79	7mC	8/30	13.2	5mC	9/30	33.26	5mC
			7/25	11.74	7mC	7/17	5.28	7mC	9/08	17.6	5mC	10/10	17.78	5mC
			7/29	10.82	7mC	7/20	6.59	6mC	9/13	20.3	5mC	11/03	8.01	0mG
			8/07	10.52	6mC	7/25	12.55	1mG	9/19	18.5	5mC		10.5	6mG
			8/22	15.81	7mC		10.04	2mG	9/25	12.8	5mC	12/02	8.7	5mC
			9/03	24.03	4mC		10.04	3mG	10/03	24.8	5mC			
			9/17	12.75	10mC		8.55	4mG	10/24	13.3	5mC			
			9/24	10.06	10mC		7.58	5mG	11/07	10.2	5mC			
			10/08	13.3	10mC		*98.58	6mG	11/27	7.6	5mC			
			11/04	6.2	10mC	8/02	10.2	6mC	12/22	4.20	5mC			
						8/09	12.97	5mC						
						8/14	13.98	6mC						
						8/21	16.78	6mC						
						8/24	12.29	8mC						
						8/28	11.77	6mC						
						8/30	11.4	6mC						
						9/05	5.48	6mC						
						9/10	8.73	7mC						
						9/12	11.79	7mC						
						9/14	11.30	8mC						
						9/20	7.53	8mC						
						9/26	7.35	10mC						
						10/03	6.88	10mC						
						10/16	6.24	10mC						
						10/30	8.95	10mC						
						11/15	9.0	10mC						

Table 3C: Annabessacook Lake Secchi Disk Visibility (South basin)

1981		1980		1979		1978		1977	
date	meters	date	meters	date	meters	date	meters	date	meters
3/19	4.2	2/20[i]	3.9	1/24[i]	5.0	1/03[i]	3.5	3/30[i]	3.6
4/22	3.6	3/26[i]	4.2	2/28[i]	4.6	5/08	3.0	5/05	2.9
5/26	4.7	4/14	2.4	3/16[i]	3.8	6/06	3.2	5/26	3.5
6/08	6.0	4/22	3.0	4/18	4.4	6/12	3.1	6/10	2.1
6/15	5.5	5/05	3.3	4/20	4.2	6/23	3.1	6/14	2.3
6/19	6.1	5/15	3.3	5/02	3.3	7/03	1.8	6/16	2.1
6/30	4.7	6/06	4.5	5/15	3.3	7/07	1.1	6/23	1.6
7/10	3.6	6/19	4.8	5/31	3.8	7/14	1.1	7/01	1.1
7/15	3.2	6/25	4.7	6/12	3.8	7/21	0.8	7/05	1.0
7/17	3.0	7/03	4.5	6/20	4.4	7/31	1.3	7/11	1.4
7/23	2.0	7/10	4.4	6/27	3.6	8/07	1.0	7/15	2.0
7/30	2.0	7/16	3.7	7/03	4.1	8/10	1.6	7/19	1.0
8/05	1.6	7/18	3.0	7/09	4.6	8/25	2.4	7/21	1.1
8/10	1.8	7/23	2.0	7/12	4.4	8/30	2.2	7/28	0.9
8/17	2.1	7/25	1.8	7/17	4.7	9/08	1.5	8/02	0.9
8/21	1.6	7/29	2.0	7/20	3.5	9/13	1.7	8/09	1.3
8/31	1.9	7/31	2.0	7/23	2.8	9/19	1.5	8/16	1.0
9/09	1.6	8/05	2.0	7/24	2.7	9/25	2.5	8/24	1.1
9/16	1.2	8/07	2.1	7/25	2.7	10/03	1.5	8/31	1.0
9/17	1.3	8/13	2.1	7/26	3.1	10/13	2.7	9/12	3.0
9/21	1.6	8/18	1.8	7/27	2.6	10/24	3.3	9/15	2.5
9/29	3.1	8/22	2.5	7/30	2.6	11/07	4.0	9/23	2.2
10/09	2.5	8/26	2.9	7/31	2.6	11/27	3.6	9/26	2.0
10/21	3.4	8/28	3.9	8/02	2.5			9/30	1.8
11/19	3.8	9/03	3.1	8/03	2.5			10/05	1.8
		9/15	2.6	8/06	2.2			10/11	2.0
		9/17	2.9	8/08	2.1			11/16	2.7
		9/24	2.8	8/09	2.0				
		10/08	3.0	8/13	2.3				
		11/04	4.5	8/14	2.4				
				8/16	2.6				
				8/20	2.8				
				8/21	2.8				
				8/22	2.9				
				8/24	3.0				
				8/28	3.0				
				8/30	3.1				
				9/05	5.0				
				9/10	4.5				
				9/12	3.7				
				9/14	3.2				
				9/17	3.3				
				9/20	3.2				
				9/26	3.4				
				10/03	3.7				
				10/16	4.3				
				10/30	3.8				
				11/15	3.8				

i = ice cover

Appendix D Cobbossee Lake Water Quality Data

Table 1D:
COBBOSSEE LAKE CHLOROPHYLL-A

South Basin, Station 1

1981			1980			1979			1978			1977		
date	ug/l	type	date	ug/l	type	date	ug/l	type	date	ug/l	type	date	ug/l	type
3/24	5.2	10mC	2/07[1]	6.88	10mC	2/22[1]	4.52	5mC	1/24[1]	3.2	3mG	7/20	1.5	2mG
	5.5	dupl	4/14	8.03	10mC	4/23	12.3	10mC		2.9	7mG	8/26	18.9	2mG
4/28	6.24	10mC	5/05	4.14	10mC	5/07	5.57	10mC	2/17[1]	1.7	3mG	9/16	16.3	2mG
	6.02	dupl	6/05	6.09	10mC	6/01	2.08	10mC		1.0	7mG	9/30	11.1	5mC
5/26	3.44	10mC	6/16	7.40	10mC		1.78	dupl	3/24[1]	10.1	3mG	10/11	13.0	5mC
6/18	2.2	10mC		7.2	dupl	6/13	6.83	10mC	6/26	5.2	5mC	11/18	6.9	5mC
7/08	3.4	8mC	6/18	6.2	10mC	6/28	3.73	10mC	8/11	8.1	5mC			
8/03	6.3	8mC	7/03	5.03	10mC	7/10	3.26	10mC	9/05	16.1	5mC			
9/02	15.1	9mC	7/10	3.70	9mC	7/27	3.75	10mC	9/26	13.0	5mC			
9/18	22.5	10mC	7/17	4.55	9mC	8/08	5.92	7mC	10/19	4.6	5mC			
10/01	11.8	10mC	7/24	5.65	8mC	8/17	12.86	8mC	11/21	11.8	5mC			
11/09	9.66	10mC	8/01	5.33	8mC	8/22	14.32	8mC						
			8/08	10.10	7mC	8/30	15.62	7mC						
			8/13	12.49	8mC	9/07	14.89	9mC						
			8/21	21.27	8mC	9/19	18.70	9mC						
			8/30	19.60	8mC	10/02	7.49	10mC						
			9/04	17.99	8mC	10/15	8.64	10mC						
			9/09	20.8	8mC	10/30	16.25	10mC						
			9/18	20.44	9mC									
			10/07	8.55	10mC									
			11/07	6.97	10mC									

North Basin, Station 2

1981			1980			1979			1978			1977		
date	ug/l	type	date	ug/l	type	date	ug/l	type	date	ug/l	type	date	ug/l	type
3/24	3.8	10mC	2/04[1]	9.63	10mC	2/22[1]	6.66	5mC	1/24[1]	2.3	3mG	7/20	1.8	2mG
4/28	7.30	10mC		8.91	dupl	4/23	13.5	10mC			5mG	8/26	19.9	2mG
5/26	6.06	10mC	4/14	2.97	10mC	5/07	5.38	10mC	2/17[1]	10.2	3mG	9/30	5.3	5mC
6/18	2.0	10mC	5/05	5.10	10mC	6/01	6.25	10mC	3/24[1]	3.9	3mG	10/11	9.6	5mC
7/08	3.0	9mC	5/29	2.89	10mC	6/13	5.92	10mC	6/04	1.9	0mG			
8/03	6.9	8mC	6/05	4.71	10mC	6/28	2.66	10mC	6/19	3.1	0mG			
9/02	20.2	8mC	6/18	3.8	10mC	7/10	2.79	10mC	6/26	3.1	5mC[2]			
9/18	10.5	10mC	7/10	3.50	9mC	7/27	3.95	10mC	7/13	1.5	5mC			
10/01	12.4	10mC	7/24	5.14	8mC	8/08	7.43	7mC	7/31	7.9	0mG			
11/09	12.26	10mC	8/06	7.39	8mC	8/22	11.63	8mC	8/11	7.1	5mC			
			8/21	20.6	6mC	9/07	36.15	8mC	9/05	13.8	5mC			
			9/04	34.58	7mC	9/19	37.81	8mC	9/26	13.7	5mC			
			9/18	30.29	9mC	10/02	4.34	8mC	10/19	4.0	5mC			
			10/07	6.79	10mC	10/15	10.33	9mC	11/21	14.3	5mC			
			11/07	6.11	10mC	10/30	14.13	10mC						

Table 2D: COBBOSSEE LAKE, South (Sta. 1): SECCHI DISK VISIBILITY

1981		1980		1979		1978		1977	
	meters		meters		meters		meters		meters
3/24	4.7	2/07[i]	6.0	2/22[i]	6.2	5/05	4.0	3/10[i]	7.2
4/28	4.1	4/14	4.6	4/23	4.1	5/26	4.3	5/12	3.7
5/25	4.4	5/05	4.6	5/07	4.0	8/11	3.7	6/28	4.2
5/26	5.0	6/05	6.8	6/01	4.6	9/05	2.3	7/08	3.4
6/07	5.8	6/18	5.3	6/13	4.1	9/26	2.0	7/20	2.0
6/10	6.3	7/03	4.6	6/28	4.8	10/19	5.0	8/05	2.0
6/18	7.1	7/10	5.3	7/10	4.9	11/21	4.2	8/26	2.0
6/20	5.7	7/17	4.8	7/27	4.1			9/16	1.9
6/27	5.9	7/24	5.0	8/08	2.9			9/30	3.9
7/05	5.6	7/27	4.0	8/17	2.7			10/11	3.5
7/08	5.8	8/01	3.2	8/22	2.2			11/18	4.0
7/12	5.1	8/07	3.6	8/30	2.3				
7/19	4.3	8/10	3.0	9/07	2.1				
7/20	4.3	8/13	2.4	9/19	2.1				
7/25	4.3	8/17	2.2	10/02	3.8				
7/27	4.3	8/21	2.2	10/15	4.6				
8/01	3.6	8/23	1.8	10/30	3.9				
8/03	3.6	8/30	1.7	11/19	4.0				
8/08	3.2	9/04	1.6						
8/12	2.7	9/06	2.2						
8/15	2.5	9/09	2.0						
8/23	2.3	9/17	2.5						
8/24	2.2	9/18	1.8						
8/29	2.2	10/07	4.0						
9/02	2.4	11/07	5.3						
9/05	2.0								
9/10	2.9								
9/18	1.7								
9/20	1.9								
10/01	2.6								
10/07	3.4								
10/15	3.6								
11/09	3.4								

Table 2D (cont.) COBBOSSEE LAKE, North (Sta. 2): SECCHI DISK VISIBILITY

1981		1980		1979		1978		1977	
	meters		meters		meters		meters		meters
3/24	5.3	2/04[1]	5.8	2/22[1]	4.6	5/05	4.7	5/12	4.3
4/28	3.9	4/14	4.9	4/23	4.3	6/04	4.6	6/28	5.2
5/26	4.2	5/05	5.0	5/07	4.6	6/19	4.0	7/08	3.3
6/10	4.9	5/29	6.1	6/01	4.0	6/26	4.3	7/20	1.9
6/18	7.1	6/05	6.9	6/13	5.3	7/05	5.2	8/05	1.7
7/08	5.7	6/18	5.8	6/28	5.1	7/13	5.2	8/26	1.5
7/20	4.5	7/10	6.8	7/10	4.9	7/31	3.5	9/16	1.8
7/27	4.0	7/24	5.5	7/27	3.7	8/07	3.2	9/30	3.5
8/03	3.6	8/06	3.3	8/08	2.6	8/11	3.8	10/11	3.9
8/12	2.4	8/21	1.9	8/22	2.3	9/05	2.1	11/18	3.8
8/24	1.1	9/04	1.1	9/07	1.2	9/26	2.1		
9/02	1.7	9/18	1.6	9/19	1.1	10/19	5.2		
9/10	2.7	10/07	3.7	10/02	3.7	11/21	3.3		
9/18	2.6	11/07	5.1	10/15	4.0				
10/01	2.5			10/30	4.3				
10/15	3.9			11/19	4.0				
11/09	3.2								

Appendix E Pleasant Pond Water Quality Data

Table 1E:

PLEASANT POND CHLOROPHYLL-A

1981			1980			1979			1978			1977		
date	ug/l	type	date	ug/l	type	date	ug/l	type	date	ug/l	type	date	ug/l	type
3/26	8.2	6mC	2/11	7.05	6mC	3/01	9.78	5mC	1/16	4.5	3mG	8/29	8.7	5mC
4/28	3.10	6mC	4/22	2.53	7mC	4/20	5.36	5mC	2/21	1.0	5mG	10/12	5.7	5mC
6/02	2.81	7mC	5/15	6.62	7mC	5/09	10.83	5mC	3/20	4.7	3mG	11/21	2.8	5mC
6/29	5.4	6mC	6/05	3.71	7mC	5/30	1.79	6mC	6/01	5.0	5mC			
8/21	9.9	6.5mC	6/19	4.8	6mC		1.31	dupl	6/29	2.7	5mC			
10/06	7.76	6.5mC	7/10	4.82	5mC	6/12	6.3	6mC	8/15	5.9	5mC			
			7/24	5.22	6mC	6/28	4.21	6mC	8/31	9.3	5mC			
			8/06	3.48	5mC	7/10	5.35	6mC	9/28	9.5	5mC			
			8/22	11.91	6mC	7/27	4.87	5mC	10/17	3.6	5mC			
			9/04	16.08	6mC		4.65	dupl	11/16	4.8	5mC			
			10/07	19.45	6mC	8/07	3.47	5mC						
				20.58	dupl	8/31	6.71	6mC						
			11/07	6.5	6mC	9/17	9.03	6mC						
						10/01	13.41	6mC						
						10/19	2.67	6mC						
						11/09	1.71	7mC						

Table 2E:

PLEASANT POND SECCHI DISK VISIBILITY (meters)

1981		1980		1979		1978		1977	
3/26	2.7	2/11	3.6	4/20	3.1	5/08	3.8	5/12	2.4
4/28	4.6	4/22	1.8	5/09	2.5	6/01	3.9	6/29	3.5
6/02	4.6	5/15	2.4	5/30	3.5	6/29	4.1	7/14	4.2
6/15	4.1	6/05	4.4	6/12	2.8	8/15	4.0	7/26	4.5
6/29	4.6	6/19	3.9	6/28	2.8	8/31	3.0	8/18	3.6
7/16	3.8	7/10	4.5	7/10	3.5	9/28	2.4	8/29	3.0
7/28	4.0	7/24	5.4	7/27	4.4	10/17	4.4	9/19	2.6
8/21	2.6	8/06	5.6	8/07	4.5	11/16	3.6	9/27	2.4
9/08	2.7	8/22	3.0	8/31	3.4			10/12	2.9
10/06	3.0	9/04	2.1	9/17	3.4			11/21	2.6
		10/07	2.0	10/01	2.5				
		11/07	3.9	10/19	3.0				
				11/09	2.4				